APPLICATIONS OF HUMAN PERFORMANCE RELIABILITY EVALUATION CONCEPTS AND DEMONSTRATION GUIDELINES

prepared for

Naval Sea Systems Command
Department of the Navy
Washington, D. C.

Applied Psychological Services
Science Center
Wayne, Pa.

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ABSTRACT

Although the improvement of equipment systems for human operation and maintenance has been stressed for many years, the actual measurement and specification of human performance reliability in concrete terms has been largely ignored. A set of computer simulation models, which assess the human performance reliability of a system while the system is in the early design stage, was previously developed. The results of trial application of these simulation models to an actual system which is under development are presented. Additionally, a set of guidelines is presented which can form the basis for a human performance reliability demonstration in future Navy systems.

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APPLICATIONS OF HUMAN PERFORMANCE READABILITY EVALUATION CONCEPTS AND DEMONSTRATION GUIDELINES

Advancing technology and changes in the role of the human in advanced equipment systems have served to reemphasize the importance of minimizing human error in system function. For example, in many advanced military systems, decision making in short, time critical situations places a heavy burden on the system operator. The operator often no longer possesses the luxury of time when he needs it most, and he often has time to waste when he needs time least. In this regard, Pettitt (1974) pointed out that:

> NWP-31, the antiship missile defense doctrine, specifies that commanding officers should delegate firing authority to evaluators during a high threat situation...COs do need to know how to delegate authority to defend their ships in rapidly developing high threat situations..The necessity to compress drastically the time required for recognition of a threat through its evaluation, consideration of weapons capabilities, weapons assignment and analysis of weapon performance, until final kill, makes it evident that bold steps must be taken. Henceforth, reactions will be measured in seconds rather than minutes. Decisions, as well as evaluations, will undoubtedly be required from the officer "on scene" at the time the threat evolved, since time will no longer permit the old "detect-evaluate-disseminate" routines established in World War II.

Trends Influencing Role of Human

At least two interrelated trends seem to affect the role of the human in advanced systems. One is the trend towards automation. The second trend, which is not mutually exclusive from the first, is technological advance. Although the two concepts, automation and technological change, possess something in common, there is also a difference between the two. Specifically, technological advance implies the effects of increased scientific and production capability regardless of whether or not the function served by the capability is automatically or manually performed. Automation, per se, may or may not involve an increase in capability. The human performance reliability effects of technological change may be different from those which result from automation.

Automation

Automation represents an attractive means for reducing personnel costs. Gaites (1974) pointed out that personnel costs now represent 42 per cent of the operating budget and 26 per cent of the total budget of the Navy. He also pointed out that each man in a modern destroyer size ship requires five tons of ship representing 500 cubic feet. Construction costs for this amount of structure approximate $25, 000, and the structure must then be maintained for the 30 year shelf life of the ship.

Siegel, Wolf, and Williams (1975) reviewed trends in automation in the Navy. Additional treatment of the data of Siegel, Wolf, and Williams has yielded the curves presented in Figure 1, which presents projected levels of automation for destroyer subsystems over the years. Quite obviously, such projections are subject to a number of assumptions, but the curves serve to point up the potential for changes in the role of the human in advanced systems.

Technological Change

One need not belabor the technological advances which have taken place over the past several decades. These technological advances have been reflected in prior ship systems. It can be assumed that they will be further reflected in new ships with consequent effects on human performance.

For example, consider electronic signal processing and specifically signal correlation and anticorrelation. Until recently, signal correlation and anticorrelation have been mostly laboratory techniques. Simply stated, a signal correlator looks for some signal which possesses a correlation with a known event. This correlation is often temporal. A signal anticorrelator looks for signals which do not have a correlation with a known event. The use of these two techniques would seem to have considerable potential for applications in many new systems such as IFF, detecting and recognizing signals from countermeasures (both active and passive), and validating the authenticity of received command messages. Such systems could, however, require highly trained personnel to serve not as links in the signal processing, but to perform advanced functions which if not completed correctly could negate system effectiveness.

Human Reliability

In answer to the pervasive need for methods for assessing, while a system is in the design state, whether or not the human in advanced man/machine systems will be able to perform his required functions, the Naval Sea Systems Command instituted a "human reliability" methods program.

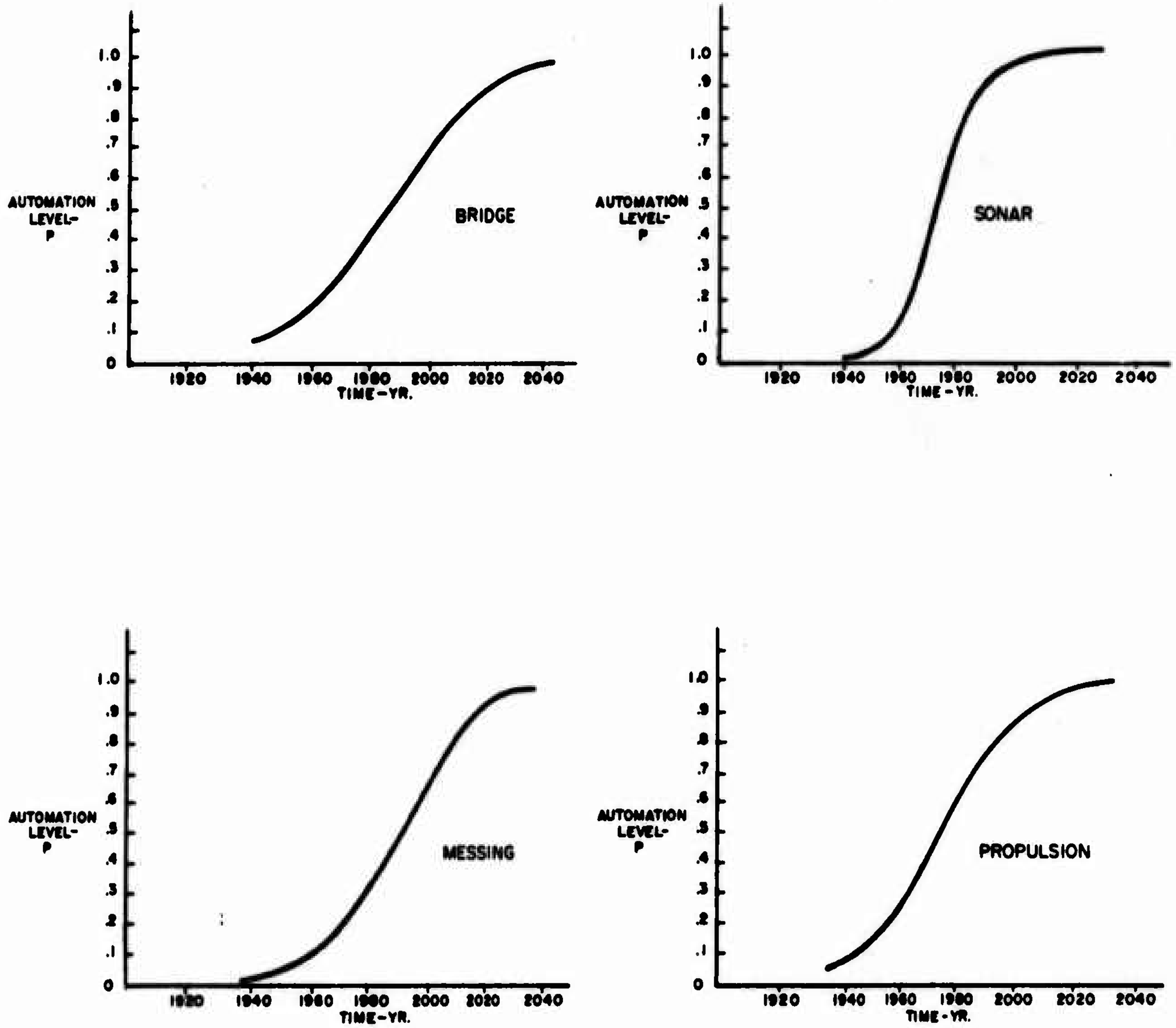

Figure 1. Projected automation trends.

Within the total human reliability program, the Applied Psychological Services has developed a number of techniques for assessing human reliability. Table 1 summarizes the methods and the sources of additional information relative to these Applied Psychological Services' developments.

Briefly, three related techniques have been developed and individually validated. The first of these is a hand calculational method for predicting the probability that a given technician will be able to perform his required functions. The technique is relatively easy to apply and can be employed without recourse to high speed calculational equipment. The second and third of these techniques are based on computer simulation. Two previously developed digital simulation models were expanded and elaborated so as to allow human reliability prediction. The first model is most appropriate for evaluations of systems which involve 1 to 3 technicians. The second model allows consideration of systems which involve from 4 to 20 technicians. In addition to a human reliability metric, this 4 to 20 man model yields measures of: (1) human availability and human mean time to repair, (2) equipment reliability, availability, and mean time to repair, and (3) system (combined human and equipment) reliability, availability, and mean time to repair.

The power of the set of approaches lies in the analytic spectrum it provides. The hand calculational technique permits rapid, desk top human reliability analysis. The 1 to 3 man simulation model may be employed when a fine sieve analysis of the tasks to be performed is sought. Individual tasks are broken down into individual component actions (e.g., throw a switch) to help bring out human oriented design defects and to quantify them. This fine grain simulation model is most appropriate for relatively short duration tasks, and generally only critical (time dependent) aspects of missions should be simulated using this simulation model. The 4 to 20 man model permits a coarser but possibly more useful level of simulation. Entire days or numbers of days can be simulated. This allows psychosocial factors, stress, level of aspiration, cross training, and similar factors to be considered in the simulation. Using all approaches on the same system allows a hierarchical approach with successive checks and independent evaluations.

Purpose of the Present Work

While previous Applied Psychological Services' work developed and evaluated the various human reliability predictive techniques, there has been no test of the methods and of their ability to make a positive contribution relative to a system which is in the design phase. The present work applied the two separate computer simulation models to the AN/SQS-26, LAMPS, AN/SQR-19 system. At the time of the analysis, the system was in the middle of the detailed design process.

Table 1

Summary of Human Reliability Predictive Methods Developed by Applied Psychological Services

Technique	*Source and Date*	*Authors*	*Comment*
Probability compounding and 1 to 3 man simulation model	Development and Test of a Human Reliability Predictive Technique for Application in Electronic Maintainability Prediction, 1971*	Federman, P.J., & Siegel, A.I.	Technique development and logic
Probability compounding and 1 to 3 man model simulation model	Validation of a Set of Human Reliability Predictive Techniques, 1973*	Siegel, A.I., & Federman, P.J.	Validation report
Computer simulation; 4 to 20 man model	A Model for Predicting Integrated Man-Machine Systems Reliability, 1974	Siegel, A.I., Wolf, J.J., & Lautman, M.R.	Technique development and logic
Computer simulation; 4 to 20 man model	A Model for Predicting Integrated Man-Machine Systems Reliability. II. Model Validation, 1975*	Siegel, A.I., Wolf, J.J., & Williams, A.R.	Validation report
Computer simulation; 1 to 3 man model	Operator Reliability for a Selected AN/SQS-26 and AN/SQR-10 Scenario, 1976*	Siegel, A.I., Leahy, W.R., & Lamb, J.C.	Application report
Computer simulation; 4 to 20 man model	Human Reliability for the AN/SQS-26, LAMPS, and AN/SQR-19 Systems, 1976*	Leahy, W.R., Siegel, A.I., & Lamb, J.C.	Application report
Demonstration	Human Performance Demonstration Guidelines, 1977*	Siegel, A.I., Leahy, W.R., & Wiesen, J.P.	———
Computer simulation and probability compounding	A Family of Models for Measuring Human Reliability, 1975**	Siegel, A.I., Wolf, J.J., & Lautman, M.R.	IEEE presentation
Various	Developing a Human Reliability Prediction Method, 1970***	Siegel, A.I.	Initial logic/overview

*= *Program Report*
**= *IEEE Symposium Report*
***= *Workshop Report*

While the previously described techniques allow early analysis and assessment of a system from the human and the integrated human/equipment points of view, a need was also apparent for an early demonstration that a given level of human performance reliability has, in fact, been achieved by the integrated design. An equipment reliability test is already required prior to the acceptance of a new Navy system or subsystem. Human reliability, however, is not included in this test. Accordingly, a set of guidelines for the conduct of a human performance reliability demonstration was developed. The human performance reliability demonstration is conjectured as an additional quality assurance technique which is implemented after initial fabrication but before system delivery. As such, the demonstration would help to assure that the required human and integrated system reliability has been, in fact, obtained.

Figure 2 shows the conceptual relationship between equipment reliability and human reliability. This scheme starts with the definition of the objectives of the system under consideration. After establishing the objectives, the design of the system and the training required to operate the system are established. The system design affects the training requirements, equipment reliability, and the human reliability. Training directly affects human reliability. Equipment reliability and human reliability both interact to affect one another and compound to produce system reliability. One important aspect of this scheme is the realization that all the major factors must be considered together in order to yield a total system which possesses adequate achieved reliability.

Results of Present Work

As indicated above, the present work possessed three separate objectives. The work performed and the end products of each effort are presented as Appendices A (1 to 3 man model application), B (4 to 20 man model application), and C (demonstration guidelines) to the present report. The results of the two simulations are similar but complementary, with the 1 to 3 man model providing specific information on failures and their cause, while the 4 to 20 man model provided indications of the effect of these failures on system performance.

There were few, if any, problems associated with the applications of the two models. About one day was involved developing each scenario simulated. The team which developed the scenarios was composed of both engineers who were familiar with the system and human factors personnel who were familiar with the models. For the 1 to 3 man model, about three days were required for input data development. Input data development for the

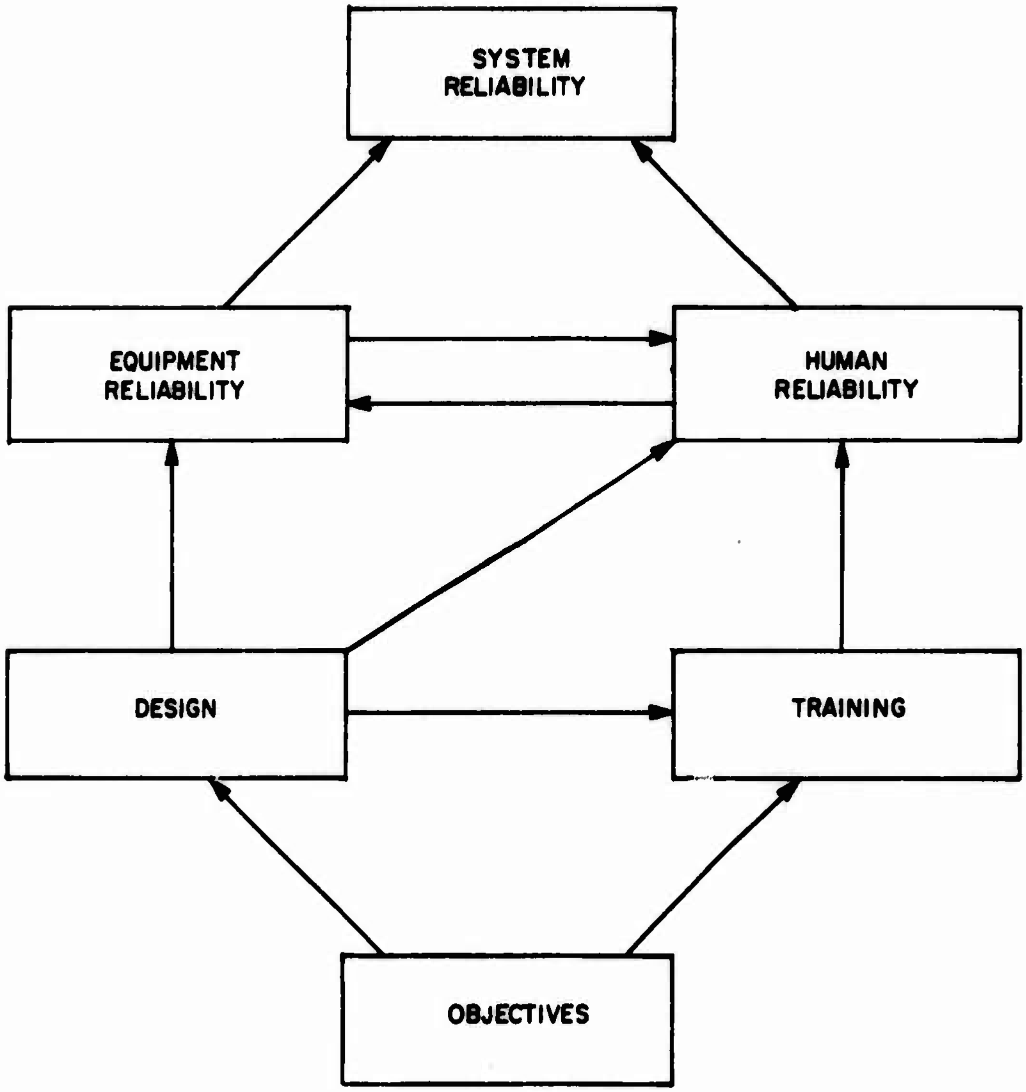

Figure 2. Interactions between equipment and human reliability.

4 to 20 man model required about 10 working days. Both model applications produced useful data relative to system improvement. Equipment system developmental personnel indicated that the results made important contributions to their thinking and that the emergent recommendations were intuitively correct. Implementation of the recommendations emerging from these human reliability analyses is now under consideration. Accordingly, at least relative to these initial tests, the utility, practicality, and ability of the methods to contribute economically to total system quality assurance seems to have been demonstrated. There has been no similar trial implementation of the demonstration guidelines. Accordingly, their utility and practicality as a system design support tool must await further development.

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APPENDIX A

Report on Application of 1 to 3 Man Model

HUMAN RELIABILITY IN A COMBINED SONAR SYSTEM

I. Operator Reliability for a Selected AN/SQS-26 and AN/SQR-XX Scenario

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ABSTRACT

A computer simulation model was applied to the acts and behaviors of the operators of the combined AN/SQS-26 and AN/SQR-XX sonar system as they perform the sequence of subtasks involved in completing a somewhat complex search, detect, locate, and track scenario including target loss and reacquisition. The results indicated 76 per cent overall success for "average" operators and nominal time allowance. This success percentage varied considerably as a function of simulated operator proficiency and time allowance. Time allowance seemed to exert a greater influence on success than simulated personnel proficiency. Areas of highest operator unreliability were indicated to be: classification, target reacquisition after target loss, target motion analysis, and cognitively oriented tasks such as speed change/course derivation.

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CHAPTER I

INTRODUCTION

Over the past several years, the Navy Sea Systems Command has been concerned with a program oriented toward the development of measures for assessing the "human reliability" in a system. To this end, the total program has developed both empirical and simulation models. Both types of model are held to be useful for predicting human reliability while a system is in the early design stage.

Human reliability is defined as that measure of human performance which when combined with equipment reliability allows one to predict total system reliability. This measure, if obtained early in the system development cycle, allows the reevaluation of equipment design, operational procedures, and maintenance procedures to promote maximal total system performance.

The present work applied one of the techniques developed within the total program to the combined AN/SQS-26 and AN/SQR-XX systems. The specific technique employed was computer simulation of operator actions through a previously developed simulation model. The model simulates the acts and behavior of the system operators/maintainers as they complete the sequence of subtasks necessary for task completion. The model's output provides information relative to total task success, time for task completion, subtasks failed within the total task, periods of stress on the operator/maintainer, and the like. The model is called the Siegel-Wolf simulation model and has been described in detail previously. However, for purposes of continuity the model is summarized below.

Description of Siegel-Wolf Model

The Siegel-Wolf model is used with a high-speed, general purpose digital computer. To employ the model, the system designer or evaluator makes an analysis of the man-machine system and the task under consideration. The performance of each operator is arranged into ordered, discrete actions called "subtasks," and for each of these certain source data are compiled. These data, together with selected parameter values (e.g., the time allotted for task performance) are introduced into the digital computer. The computer sequentially simulates, according to the rules of the model, the "performance" of each subtask by each operator. The normal sequence of subtasks, whether linear or non-linear, may be modified if actions have to be skipped or repeated due to failure by either operator at a subtask or as a result of operator decisions. A simulation is completed when the operators either use all allotted time or successfully complete the task. During the course of the computer's performance" of the task, results are recorded indicating the areas of operator overload, failure, idle time, peak stress, etc., for the given set of selected parameters. Repetitions of the simulation, with different parameter values, yield a range of records. If the results indicate modifications to the design of the system, new designs may be similarly tested to determine the extent of improvement brought about by the modifications.

The other data required by the computer in advance of the simulation are the parameters and initial conditions. These permit the adjustments of critical variables and the consequent determination of the range of their effects. In order to simulate intra- and inter-individual differences of performance, the simulation of any individual subtask is based, in part, on a random process. Because of this stochastic effect, it is necessary to repeat the simulation of a task many times in order to obtain sufficient performance data for each set of conditions. The parameter N is used to indicate the *number of times a given task is to be simulated;* there are N simulations (or N iterations) per computer 'run'.

To use the model twelve items of input data are required for each subtask ($i = 1, 2, \ldots, n$) and each operator ($j = 1, 2$). These data may be derived from such procedures as task analysis, literature search, or personal interviews. The required input data for each operator are:

1. *average subtask execution time,* $\bar{t}_{ij}$*:* the average time required by the jth operator to perform subtask i. This average value represents the case in which the operator is under no stress.

2. *average standard deviation,* σ_{ij}*:* taken around the $\bar{t}_{ij}$ for the average operator while not under stress.

3. *average subtask probability of success,* $\bar{p}_{ij}$*:* the probability that the average operator, j, while not under stress, can perform subtask i successfully.

4. *indication of subtask essentially,* E_{ij}*:* an indicator specifying whether or not the successful performance of subtask i by operator j is essential to successful completion of the task. This datum allows the computer to identify and ignore non-essential subtasks during "highly urgent" conditions.

5. *idle time requirement,* I_{ij}: the point in time before which operator j is not permitted to begin subtask i.

6. indication of whether subtask i is a *decision subtask* or a *normal action subtask.*

7. *subtask number,* $(i,j)_f$ to be performed next by an operator j if he fails at subtask i or if he chooses the *first* of two alternative courses in a decision subtask.

8. *subtask number,* $(i,j)_s$ to be performed by an operator j if he succeeds on subtask i, or chooses the *second* alternative course in a decision subtask.

9. *subtask number,* d_{ij} *(mnemonic delay)* which must be successfully completed by his *partner* before an operator j can begin subtask i. By proper selection of d_{ij} values, it is possible to cause either operator to "wait" until his partner has completed a stipulated subtask successfully. Thus, "waiting" for one's partner is simulated differently from time spent "idling" until a fixed time as in 5 above.

10. indication of whether or not subtask i for operator j is a *special subtask* in which the operators communicate with each other.

11. *time,* T^E_{ij}, *required to perform all remaining essential subtasks* (including i) at average execution times, assuming no failure. With no branching or decisions:

$$T^E_{ij} = \sum_{i=1}^{n} \bar{t}_{ij}.$$

12. *time,* T^N_{ij}, *required to perform all remaining non-essential subtasks* (including i) at average execution times, assuming no failures.

Three pairs of parameters may be varied from run to run in order to evaluate either the model on a man-machine system. The *stress thresholds*, M_j, one for each operator, may be considered as the operator's "breaking point." For example, an M_j value of 2.0 indicates that the operator begins to become slower and less accurate at the point at which he has more than twice as much to do (at average speed) as he has time available. Prior to this point, any added backlog of essential subtasks induces stress which affects the operator's actions so that they become faster and more accurate.

The parameters, T_j, are the *total times allotted to each operator for performance of the whole task*. For a two man team, the task is considered to have been successfully completed if both operators complete all required subtasks within the time specified by the larger of the two values.

The parameters, F_j, which account for variance among individuals, are termed the *individuality factors* for the two operators. F_j is a multiplicative factor with a value of unity for the average operator. For faster or more highly motivated operators $(F_j < 1)$, and for slower operators $(F_j > 1)$.

The Simulation Sequence

Having stored the program, parameters, and initial conditions, the computer begins processing the data sequentially. It determines the sequence of subtasks to perform in accordance with $(i,j)_s$ and $(i,j)_f$ input data. Its determination of which operator to simulate at any given time in the sequence depends upon T^U_{ij}, the total time used by operator j while "performing" all subtasks from the start of the simulation through subtask $i-1$. The operator having the smaller T^U_{ij} value is selected, and his next subtask is simulated.

If waiting is required, the sequence continues using data for the other operator. Then, a determination is made as to whether the operator must idle until an amount of time I_{ij} has elapsed from the beginning of the simulation. If idling is required, the idle time $I_{ij} - T^U_{ij}$ is recorded, totals accumulated, T^U_{ij} set equal to I_{ij}, and the control returned to determine which operator to simulate next. If no idling is required, a determination is made of whether or not subtask i is a communication subtask. If it is, the operators are synchronized by setting the total time used by both at that of the one who has taken longer. This may result in a wait for either operator and is treated as the wait described above.

Urgency and Stress

Following the synchronization of the operators, or if the subtask is not a communication subtask, one of three states of "*urgency*" is determined for each operator, based upon the remaining time available to him for completing the task and the average time required to complete it if no failures occur:

1. The situation is *non-urgent* when sufficient time remains to complete all remaining subtasks.
2. The *urgent* state occurs if the time available is insufficient to complete all remaining essential subtasks.
3. The situation is *highly urgent* if there is insufficient time available for completing even the remaining essential subtasks.

In the urgent and highly urgent conditions, the computer ignores the non-essential subtasks.

Following the determination of the degree of "urgency," the *stress* condition is calculated. Current psychological theory suggests that emotion or stress acts as an organizing agent on behavior up to a certain point, and beyond it as a disorganizing agent. Accordingly, the model recognizes an organizing effect on operator performance as long as s_{ij} (the stress upon operator j just prior to his performance of subtask i) is less than a threshold value M_j: if s_{ij} exceeds M_j, the effect is disorganizing. During non-urgent and urgent conditions s_{ij} is defined as equal to unity; when the situation is highly urgent, stress is defined as the ratio of the sum of the average execution times for the remaining essential subtasks to the total time remaining:

$$s_{ij} = \frac{\overline{T}^{E}_{ij}}{T_j - T^{U}_{ij}}$$

In other words, stress is the ratio of how much is left to do to the amout of time available in which to do it.

Since each operator has an individual time limit on his performance and a task failure occurs only when the larger of these limits is exceeded, it is possible for the simulation to continue with one operator (arbitrarily selected as operator 1) having exceeded his limit. Should this be the case, the stress condition of this operator is set equal to his threshold value, M_j, for the remainder of the simulation.

Subtask Success and Failure

The model assumes that the actual probability of successful performance of a given subtask, p_{ij}, is a function of $\bar{p}_{ij}$, s_{ij}, and M_j, as follows:

$$p_{ij} \begin{cases} \bar{p}_{ij} + \dfrac{(1 + \bar{p}_{ij})\,(s_{ij} - 1)}{M_j - 1} & \text{if } s_{ij} < M_j \\ \bar{p}_{ij}\,(s_{ij} + 1 - M_j) + (M_j - s_{ij}) & \text{if } M_j \leq s_{ij} \leq M_j + 1 \\ 2\bar{p}_{ij} - 1 & \text{if } s_{ij} > M_j + 1 \end{cases}$$

Thus the probability of success increases linearly with stress from a value of $\bar{p}_{ij}$ until it assumes a value of unity at the stress threshold. Following this point, the probability assumes the average value, $\bar{p}_{ij}$ after which it decreases linearly until, when stress has a value equal to $M_j + 1$, it levels off at a value which is decreased from $\bar{p}_{ij}$ by an amount equal to $1 - \bar{p}_{ij}$. In order to determine actual success or failure for any subtask, the computer generates a pseudo-random number, R_3, uniformly distributed over the unit interval from R_2. The operator is considered to have performed the subtask successfully if R_3 is less than p_{ij}; otherwise he is assumed to have failed. This implies that there will be a failure with probability, $\bar{p}_{ij}$, in the long run.

Other Details of the Simulation Process

An operator may find it desirable, or external conditions may require him, to select one of several alternative courses of action. The *decision subtask*, incorporated to enable such branching, skipping, and looping, causes the computer to select the next subtask without "consuming operator time." Decision subtasks may be placed anywhere in the sequence. For these, $\bar{t}_{ij}$, σ_{ij}, and essentiality have no meaning. The t_{ij} calculation is bypassed and the last pseudo-random number, R_3, from the previous subtask is compared against the p_{ij} of the decision subtask. Therefore, the next subtask to be performed as a result of the decision, is subtask $(i,j)s$ with probability $\bar{p}_{ij}$, or subtask $(i,j)f$ with probability $1 - \bar{p}_{ij}$.

In certain subtasks, such as placing a cursor on a target, several trials for the same action are usually required although a single action may occasionally be successful. These subtasks are treated by the computer as requiring a single control action with a relatively low probability of success. The probability of success on a single trial is determined, using the formula that if p is the probability of a success on a single trial and $p*$ is the probability of at least one success after n trials then $p = 1 - \sqrt[n]{(1 - p*)}$.

Operators are assumed to remember and execute the correct sequence of subtasks. However, the possibility of one or both operators neglecting a subtask or rearranging the performance may be studied by additional runs using the different sequences concerned. A change in the predetermined sequence of subtasks in the event of emergency can be dealt with by establishing special "danger" sequences to be simulated.

Validation of the Siegel-Wolf Model

The Siegel-Wolf model has received a wide variety of validations and verifications and possesses a history of use relative to sonar systems. In the empirical validations the model's output has been compared with real life data. Examples of these validations are reported in Federman and Siegel (1973), Siegel and Macpherson (1967), Siegel and Wolf (1963), and Siegel, Wolf, and Sorenson (1962). In all of these validations, reasonable conformity between the model's predictions and real life criterion data has been found.

The Present Simulations

Systems Simulated

The system simulated in the present model application is a new sonar system combining the best features of two systems--the AN/SQS-26 and the AN/SQR-XX sonar systems. The new system allows an increase in capability through sensor, signal processing, and information display/processing improvement. The new system will provide capability in a wide variety of modes with many operator options for a wide variety of situations and circumstances. A detailed description of the capabilities of the new system is not given here because of "security" considerations.

The Mission Simulated

As a test of the ability of the operators of the combined AN/SQS-26 and AN/SQR--XX sonar system to complete the required subtasks in a typical, time bound scenario, a 24 minute "mission" was selected. The scenario requires a reasonable variety of operator actions and is performed under reasonably high stress conditions. The scenario was derived in consultation with personnel at the Navy Underwater Systems Center, New London, Conn. Figure 1-1 pictorially presents a time line history of the tracks of the vessels during the derived scenario. At the start (T + 0), own ship is on a 045^{o} course at a speed of 20 knots. At this time, two consoles are manned (one operator at each).

In order to fix the target ship, the AN/SQS-26 operator requests a course change. Our ship changes course to a 090^{o} heading at T + 5 minutes. This course change consumes about two minutes. After the course change, the target's location is determined and these data are entered into the computer. At T + 10, the target ship stops dead in the water and the AN/SQS-26 operator recommends a new heading (000^{o}).

At T + 14 minutes, the target ship begins a hard turn to port and own ship reacts by turning to 045^{o} at T + 15 minutes. At T + 18 minutes, own ship reduces speed to 10 knots. Target contact is lost at T + 20 minutes at which time the target ship passes directly under own ship. The final simulated subtasks are target reacquisition.

The sequence of subtasks performed by each operator during this time interval is presented in Tables 1-1 and 1-2. The subtask sequence is placed on a time line in Figure 1-2.

Figure 1-3 presents the task data of Tables 1-1 and 1-2 as employed in the simulation.

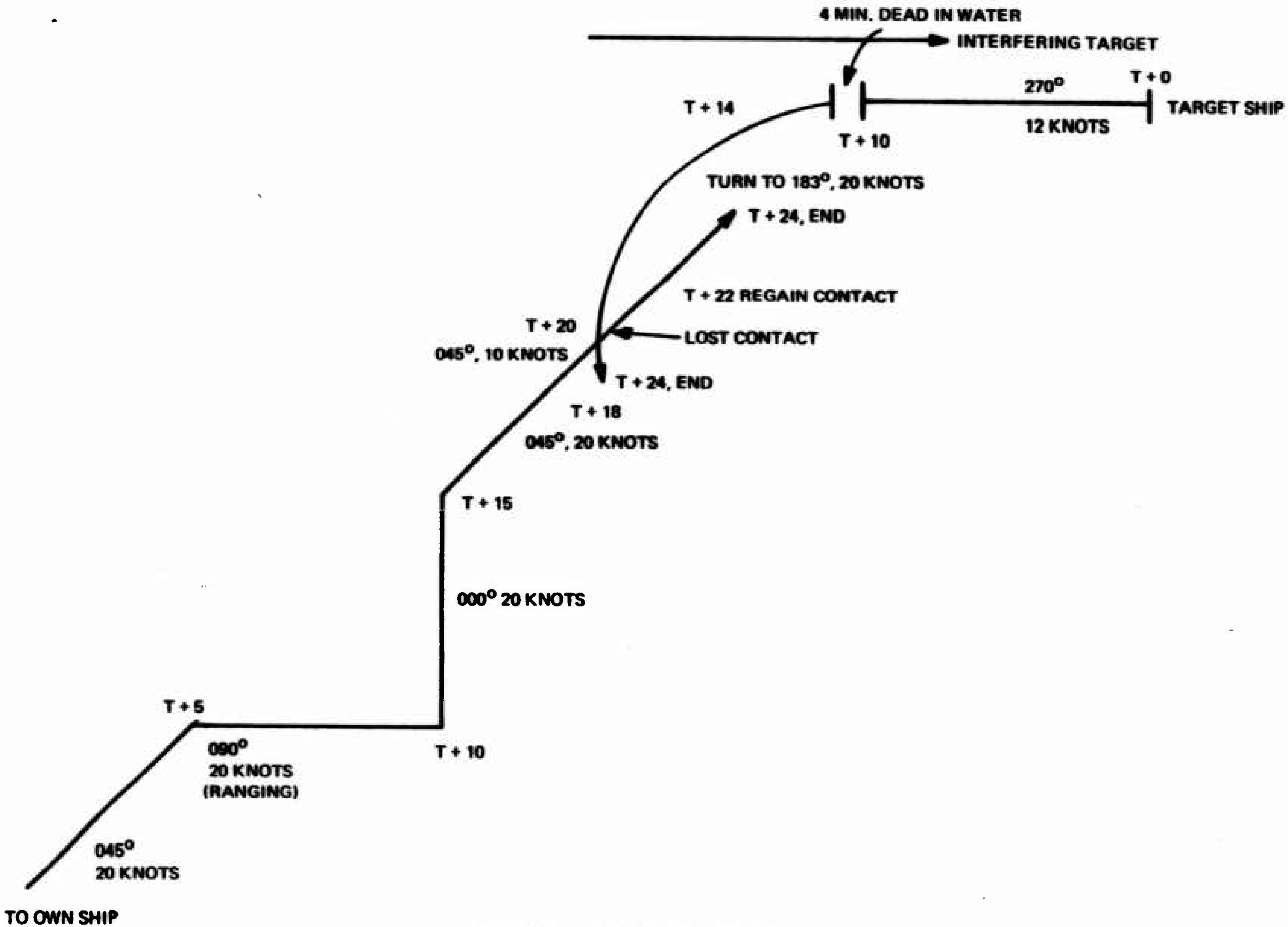

FIGURE 1-1. SCENARIO SEQUENCE

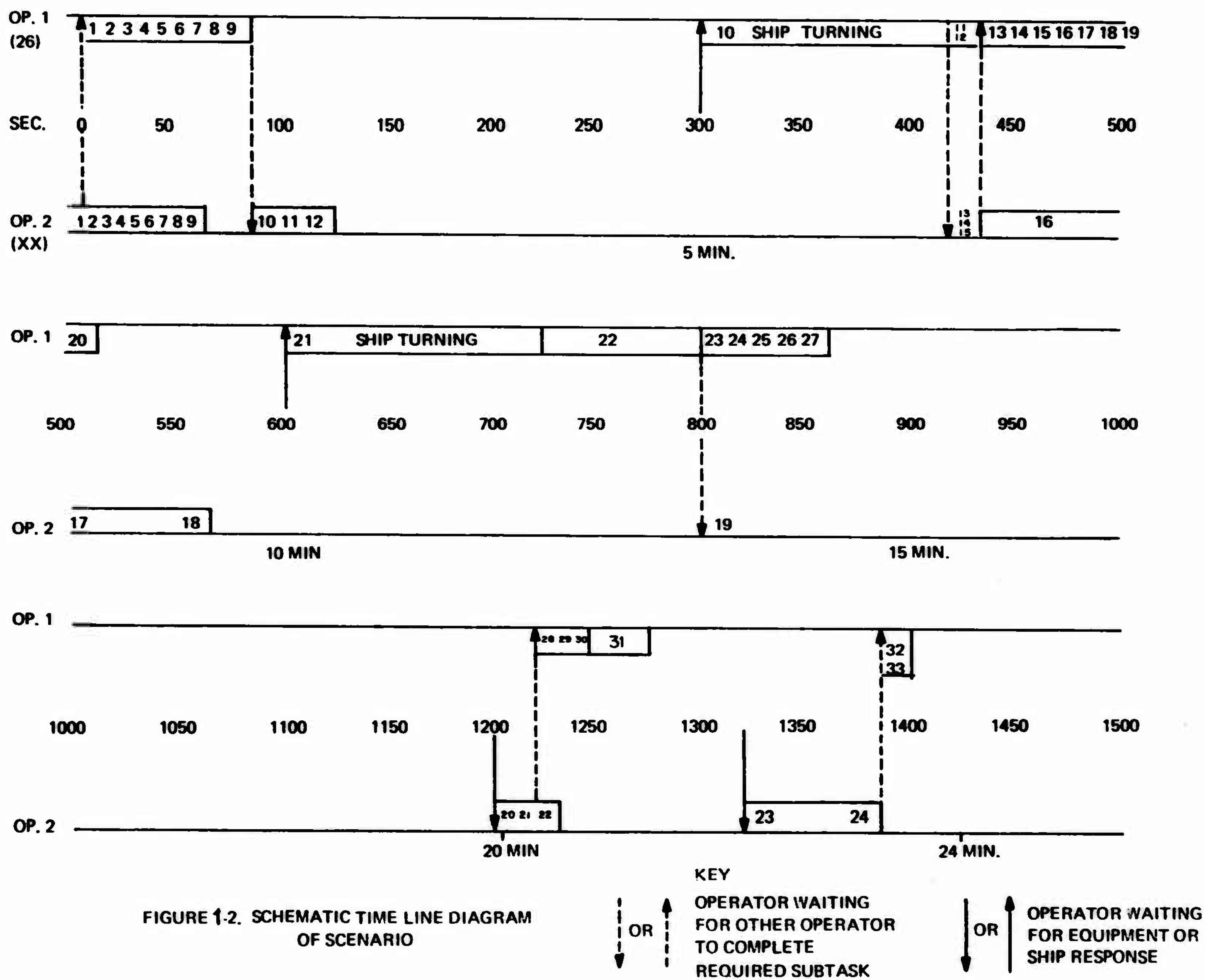

FIGURE 1-2. SCHEMATIC TIME LINE DIAGRAM
OF SCENARIO

Table 1-1

Sequence of AN/SQS-26 Operator Subtasks Simulated (Operator 1)

1. Acknowledge detection report
2. Select sit. sum.
3. Report sonar contact
4. Locate target on PNB
5. Report bearing
6. Determine course change
7. Recommend course change
8. Select fine bearing
9. Direct fine bearing
10. Ship turn - 2 minute wait
11. Slew curser to measure bearing
12. Read digital display
13. Reply to XX bearing report
14. Input 26 bearing to computer
15. Input XX bearing to computer
16. Read digital range estimate
17. Report to CONN
18. Project track
19. Slew cursor
20. Recommend projected course
21. Ship turning-2 minute wait
22. Note change in bearing rate
23. Respond to XX report
24. Recommend intercept course
25. Report new intercept course
26. Derive speed change
27. Recommend speed change
28. Acknowledge report lost contact
29. Report to CONN
30. Change bearing CRT to section PNB
31. Search for target
32. Acknowledge report recontact
33. Report to CONN

Table 1-2

Sequence of AN/SQR-XX Operator Subtasks Simulated (Operator 2)

1. Report detection
2. Slew cursor
3. Tag target
4. Select single beam on lower CRT
5. Assign DEMON
6. Slew cursor
7. Select bearing correction
8. Select harmonic cursor
9. Measure harmonics
10. Acknowledge fine bearing instruction
11. Select fine bearing
12. Call up CRT profile
13. Slew cursor to measure bearing
14. Read digital display
15. Report bearing to supervisor
16. Classify target
17. Notice intervening target
18. Report interfering target
19. Report classification
20. Decide contact loss
21. Report lost contact
22. Select vector
23. Search
24. Report contact

TASK DATA FOR OPERATOR 1

TASK NO	TASK TYPE	NON ESS	PRECEDENCE TASK	PRECEDENCE TIME	NEXT-TASK SUC	NEXT-TASK FAIL	AVERAGE TIME	TIME DEV	PROB. SUC	TIME REMAINING ESS	TIME REMAINING NON-ESS	SPEC. CODE	JUMP OP1	TASK OP2
1		E	1	0.	2	1	4.560	2.440	0.990	1391.150	0.	0	0	0
2		E	0	0.	3	2	4.200	1.020	0.990	1386.540	0.	0	0	0
3		E	0	0.	4	3	5.220	2.730	0.990	1382.300	0.	0	0	0
4		E	0	0.	5	4	7.000	2.500	0.500	1377.030	0.	0	0	0
5		E	0	0.	6	5	5.380	3.120	0.950	1363.030	0.	0	0	0
6		E	0	0.	7	6	35.000	12.000	0.970	1356.940	0.	0	0	0
7		E	0	0.	8	7	7.200	3.800	0.950	1320.760	0.	0	0	0
8		E	0	0.	9	8	4.200	1.020	0.990	1313.130	0.	0	0	0
9		E	0	0.	10	9	7.200	3.800	0.950	1303.940	0.	0	0	0
10	E	E	0	300.00	11	10	120.000	30.000	1.000	1097.340	0.	0	0	0
11		E	0	0.	12	11	3.800	0.430	0.680	977.340	0.	0	0	0
12		E	0	0.	13	12	1.200	0.400	0.750	971.750	0.	0	0	0
13		E	15	0.	14	13	4.560	2.440	0.990	965.940	0.	0	0	0
14		E	0	0.	15	14	21.000	5.100	0.950	961.330	0.	0	0	0
15		E	0	0.	16	15	16.800	4.080	0.960	939.220	0.	0	0	0
16		E	0	0.	17	16	1.200	0.040	0.750	921.720	0.	0	0	0
17		E	0	0.	18	17	10.500	5.500	0.950	920.120	0.	0	0	0
18		E	0	0.	19	18	4.200	1.020	0.990	909.070	0.	0	0	0
19		E	0	0.	20	19	3.800	0.430	0.680	904.830	0.	0	0	0
20		E	0	0.	21	20	10.500	5.500	0.950	899.240	0.	0	0	0
21	E	E	0	600.00	22	21	120.000	30.000	1.000	797.340	0.	0	0	0
22		E	0	0.	23	22	60.000	20.000	0.750	677.340	0.	0	0	0
23		E	15	0.	24	23	4.560	2.440	0.990	597.340	0.	0	0	0
24		E	0	0.	25	24	20.000	12.000	0.900	592.780	0.	0	0	0
25		E	0	0.	26	25	7.360	4.140	0.950	570.520	0.	0	0	0
26		E	0	0.	27	26	10.000	10.000	0.700	562.250	0.	0	0	0
27		E	0	0.	28	27	4.560	2.440	0.990	547.960	0.	0	0	0
28		E	21	0.	29	28	4.560	2.440	0.990	182.630	0.	0	0	0
29		E	0	0.	30	29	4.560	2.440	0.990	179.020	0.	0	0	0
30		E	0	0.	31	30	16.300	4.080	0.960	173.410	0.	0	0	0
31		E	0	0.	32	31	10.000	2.500	0.320	155.910	0.	0	0	0
32		E	24	0.	33	32	5.220	2.780	0.990	10.540	0.	0	0	0
33		E	0	0.	0	33	5.220	2.730	0.990	5.270	0.	0	0	0

TASK DATA FOR OPERATOR 2

TASK NO	TASK TYPE	NON ESS	PRECEDENCE TASK	PRECEDENCE TIME	NEXT-TASK SUC	NEXT-TASK FAIL	AVERAGE TIME	TIME DEV	PROB. SUC	TIME REMAINING ESS	TIME REMAINING NON-ESS	SPEC. CODE	JUMP OP1	TASK OP2
1		E	0	0.	2	1	5.880	3.120	0.950	1397.340	0.	0	0	0
2		E	0	0.	3	2	3.800	0.430	0.680	1391.150	0.	0	0	0
3		E	0	0.	4	3	4.200	1.020	0.990	1385.560	0.	0	0	0
4		E	0	0.	5	4	4.200	1.020	0.990	1381.320	0.	0	0	0
5		E	0	0.	6	5	16.300	4.080	0.960	1377.030	0.	0	0	0
6		E	0	0.	7	6	3.800	0.430	0.680	1359.530	0.	0	0	0
7		E	0	0.	8	7	4.200	1.020	0.990	1353.990	0.	0	0	0
8		E	0	0.	9	8	4.200	1.020	0.990	1349.750	0.	0	0	0
9		E	0	0.	10	9	3.800	0.430	0.680	1345.510	0.	0	0	0
10		E	9	0.	11	10	4.560	2.440	0.990	1301.360	0.	0	0	0
11		E	0	0.	12	11	4.200	1.020	0.990	1296.750	0.	0	0	0
12		E	0	0.	13	12	4.200	1.020	0.990	1292.510	0.	0	0	0
13		E	10	0.	14	13	3.800	0.430	0.680	977.340	0.	0	0	0
14		E	0	0.	15	14	1.200	0.400	0.990	971.750	0.	0	0	0
15		E	0	0.	16	15	4.560	2.440	0.990	970.540	0.	0	0	0
16		E	0	0.	17	16	90.000	60.000	0.700	965.940	0.	0	0	0
17		E	0	0.	18	17	30.000	10.000	1.000	837.370	0.	0	0	0
18		E	0	0.	19	18	4.560	2.440	0.990	807.370	0.	0	0	0
19		E	22	0.	20	19	4.560	2.440	0.990	597.340	0.	0	0	0
20		E	0	1200.00	21	20	10.000	1.000	0.990	197.340	0.	0	0	0
21		E	0	0.	22	21	4.560	2.440	0.990	187.240	0.	0	0	0
22		E	0	0.	23	22	4.200	1.020	0.990	182.630	0.	0	0	0
23		E	0	1320.00	24	23	60.000	60.000	0.990	77.340	0.	0	0	0
24		E	0	0.	25	24	5.330	3.120	0.950	15.730	0.	0	0	0
25		E	0	0.	0	0	0.	0.	1.000	0.	0.	0	0	0

Figure 1-3. Task analytic input data.

CHAPTER II

SIMULATIONS COMPLETED, RESULTS, AND DISCUSSION

On the basis of the scenario and operator actions described in Chapter I, a number of simulations were completed in order to determine operator reliability in the combined AN/SQS-26 and AN/SQR-XX sonar system. Fifteen simulation runs of 100 iterations each were completed. Within the 15 runs, operator teams at five proficiency levels (speeds) were simulated at three total time allowances. The 1440 second (24 minute) time allowance is considered to be the nominal case with a shorter (1380 seconds) and a longer (1500 seconds) time limit representing "harder" and "easier" situations respectively. Operator proficiency combinations ranging from reasonably "above average" to well "below average" were included. The proficiency value equal to 1.0 represents the "average" team with values above 1.0 representing poorer proficiency and values below 1.0 representing better proficiency. Table 2-1 presents the parameters varied in the various simulation runs.

Table 2-1

Simulation Runs Completed

Run No.	Operator 1 Proficiency (F)	Operator 2 Proficiency (F)	Time Allowed (Secs.)
1	.9	.9	1440.
2	1.0	1.0	1440.
3	1.0	1.1	1440.
4	1.1	1.1	1440.
5	1.2	1.2	1440.
6	.9	.9	1380.
7	1.0	1.0	1380.
8	1.0	1.1	1380.
9	1.1	1.1	1380.
10	1.2	1.2	1380.
11	.9	.9	1500.
12	1.0	1.0	1500.
13	1.0	1.1	1500.
14	1.1	1.1	1500.
15	1.2	1.2	1500.

Per Cent Success

Figure 2-1 presents the percentage of success for the simulated operators as a function of team proficiency when the time allowed varied from 23 minutes to 25 minutes. The overall effect of reducing the time allowed for completion of all essential subtasks was clearly to reduce the percentage of successful task completions. This effect seems quite reasonable. Figure 2-2, which presents the mean percentage of success at each time allowance, indicates a close linear relationship between time allowed and mean percentage success. Increasing the time allowance from 23 to 25 minutes caused the success percentage to increase from 55 per cent to 94 per cent.

The obtained mean success percentage as a function of simulated team proficiency level is shown in Figure 2-3. The simulated results suggested overall success percentage, in terms of the criteria employed, of about 76 per cent for an "average" (F= 1.0) operator team. Increasing the team proficiency from F= 1.2 (low proficiency) to F= 0.9 (high proficiency) caused about an eight per cent increase in success. Accordingly, for the time allowance range simulated and the team proficiency range considered, time allowance exerted a greater effect on success percentage than team proficiency.

Total Work Time

Total time used (actual work time) represents another criterion which may be used as an index of operator performance. This measure sometimes reflects changes in system performance when percentage success appears to be insensitive.

Figure 2-4 presents the simulation results relative to the simulated subtask sequence as a function of time allowed. With a smaller amount of time allowed, we would expect the team to come under stress, work faster, and complete all essential subtasks earlier. This anticipated trend was indicated. The 23 minute time allowance (1380 seconds) provided a noticeable drop in time used, while there was only slight difference in total time used between the 24 and the 25 minute time allowances. The latter indication seems to suggest that the 24 minute time allowance was sufficient most of the time. Accordingly, the 24 minute allowance induced onlyslightly more stress than the 25 minute condition. An F= 0.90 team is theoretically about 30 per cent more proficient than a F= 1.2 operator team. The simulation results indicated only about a 1 per cent difference in total time used for these two types of teams.

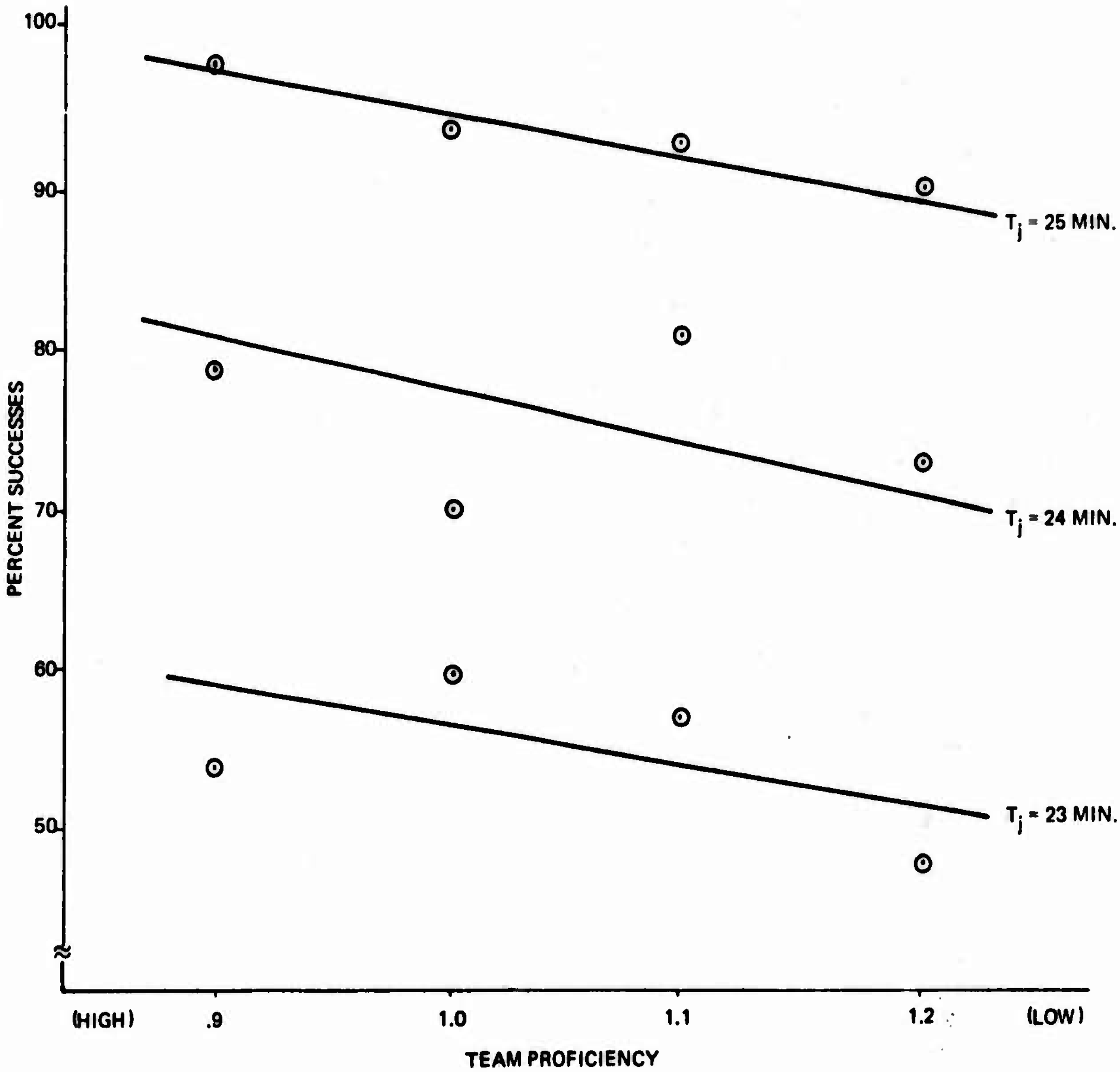

FIGURE 2-1. PERCENTAGE OF SUCCESS WITH THREE LEVELS OF TIME ALLOWED AND FOUR TEAM PROFICIENCY LEVELS

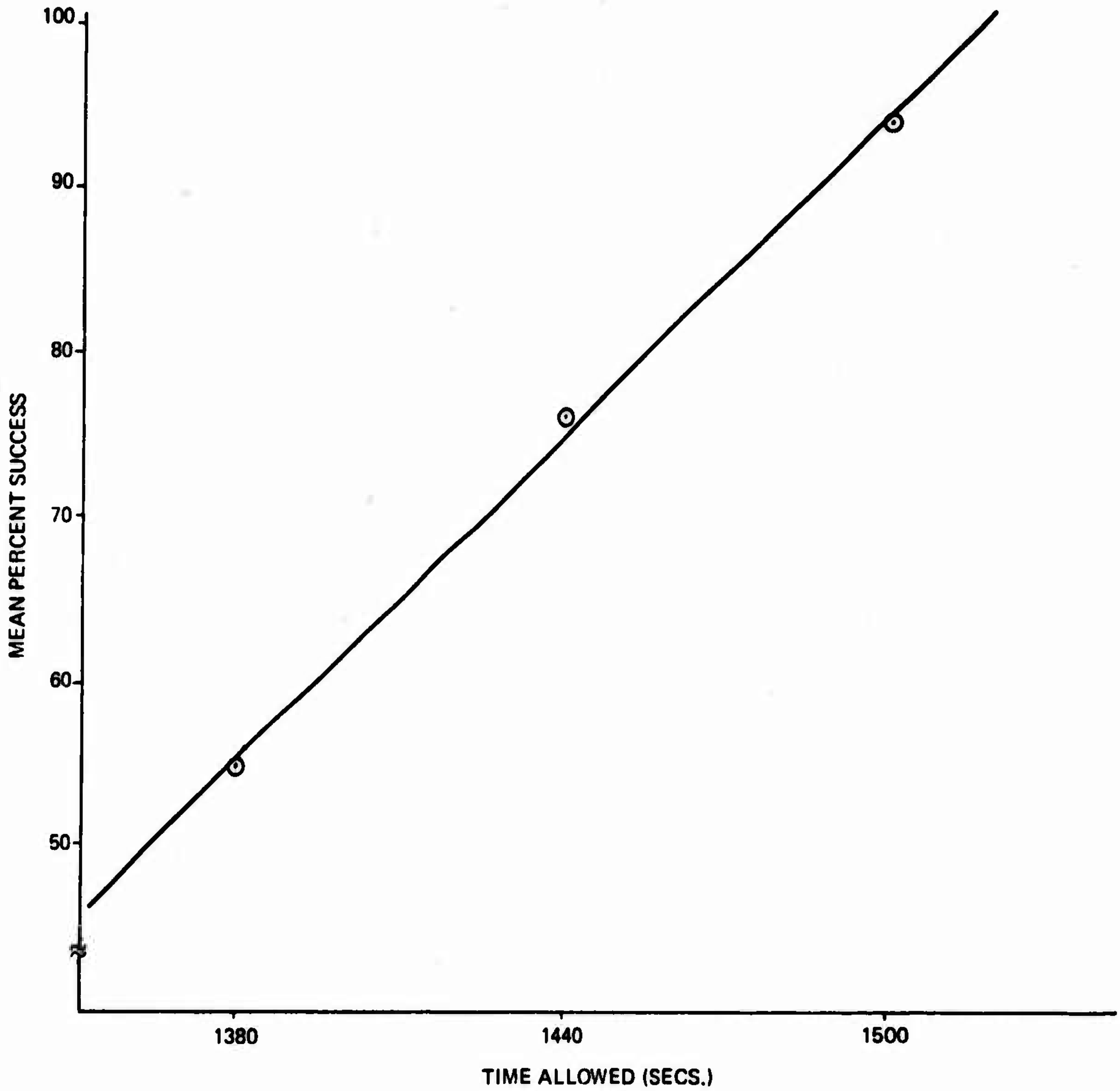

FIGURE 2-2. MEAN PERCENTAGES OF SUCCESS AT THREE TIME ALLOWANCES

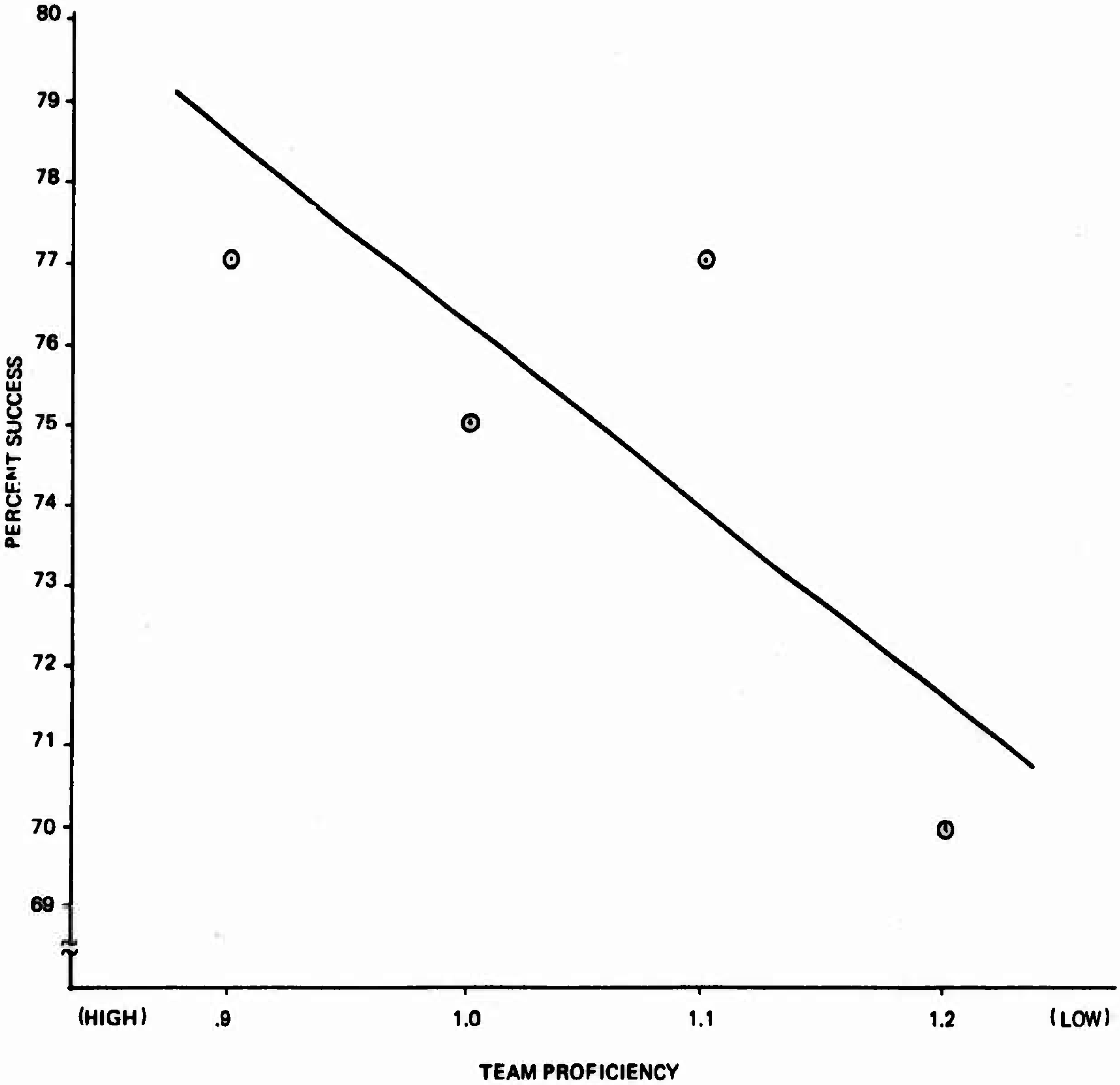

FIGURE 2-3. PERCENTAGE OF SUCCESS AT FOUR OPERATOR SPEEDS

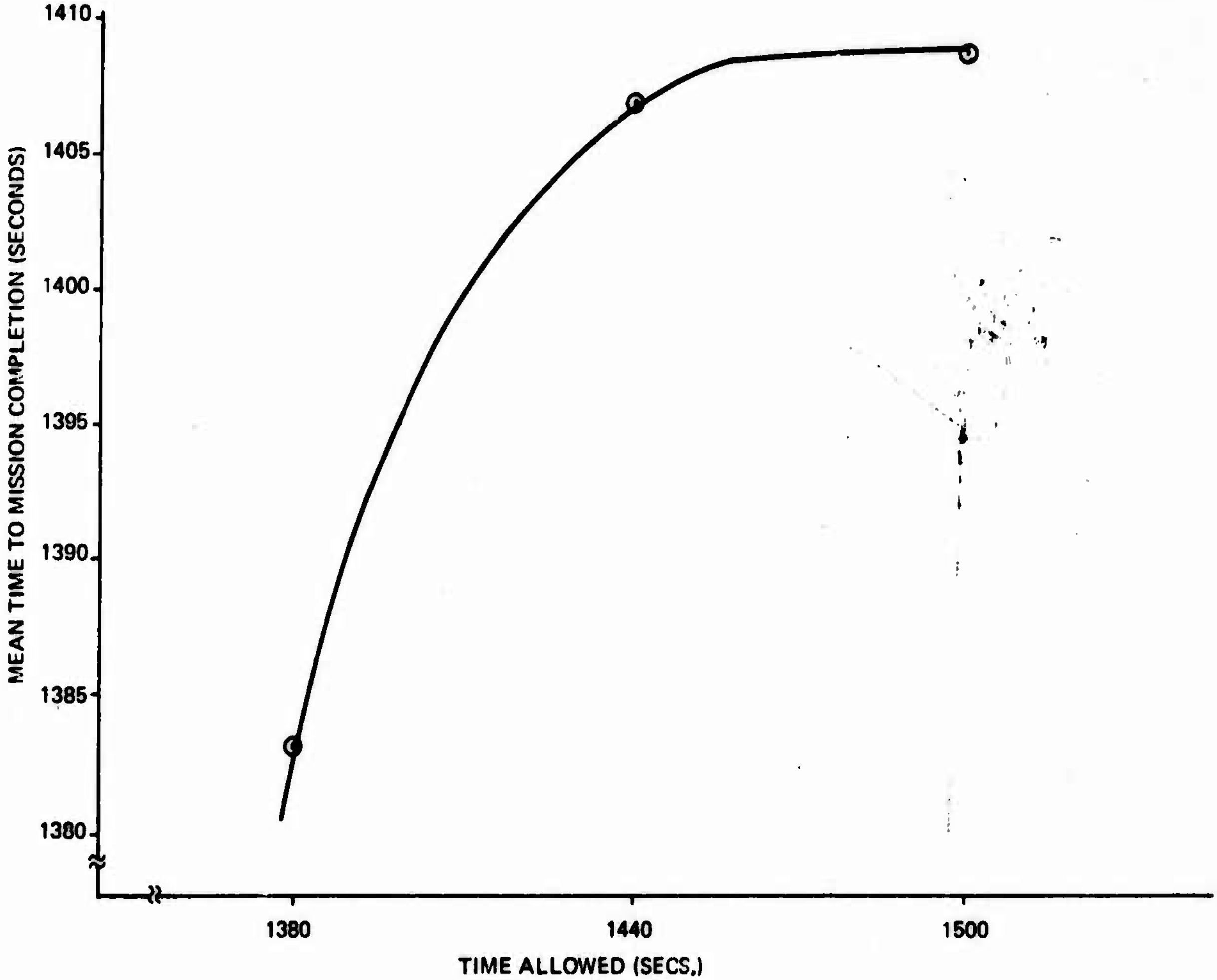

FIGURE 2-4. EFFECT OF TIME ALLOWED FOR MISSION SUCCESS ON TIME USED

The small size of this difference seems to rest on the fact that the mission scenario included a number of time waits for own ship maneuver response. There was enough waiting time so that the effects of operator proficiency were masked when total time used formed the basis for the comparison.

Task Failure Frequency

The subtasks failed most frequently by the simulated operator team provide insight into areas of potential system improvement. Equipment changes or improved training can often improve system performance once the problem areas are identified. The three most frequently failed subtasks for operator 1 are presented in Table 2-2.

Table 2-2

Subtasks Failed Most Frequently by Operator 1

Subtask Number	Times Failed/100 Iterations	Description
31	240	Search for target (after loss of contact)
4	111	Locate target on PNB
26	47	Derive speed change

The two tasks which were most frequently failed by operator 1 involved signal detection.

The third most frequently failed subtask was "derive speed change." The subtask involves slightly complex cognitive activity, as we understand the subtask. The process of performing this calculation might be reviewed from the point-of-view of job aids which might increase its success probability on the first attempt.

The three subtasks failed most frequently by operator 2 are presented in Table 2-3.

Table 2-3

Subtasks Failed Most Frequently by Operator 2

Subtask Number	Times Failed/100 Iterations	Description
13	47	Slew cursor to measure bearing
2	47	Slew cursor
16	43	Classify target

For operator 2, the tracking subtasks, along with the target classification subtask, were the high failure frequency of subtasks. The classification subtask is known to be quite difficult and seems an area where computer guiding might provide significant failure savings.

While subtask failure frequency is important in allowing insight relative to where errors may be made by an operator, the time lost in repeating or touching up tasks failed provide insight into consequences of these errors. The subtasks with the greatest amount of repetition time due to failure for operator 1 are presented in Table 2-4.

Table 2-4

High Failure (Repetition) Time Subtasks for Operator 1

Task Number	Failure Time*	Description
31	2324.21	Search for target (after loss of contact)
22	1589.12	Note change in bearing rate
4	809.93	Locate target on PNB
26	410.69	Derive speed change
24	257.39	Recommend intercept course

**Times are across 100 iterations.*

The subtasks which resulted in the most repetition time due to failure on the first attempt by operator 1 were those which require signal detection and target motion analysis. The latter is an obvious area in which job aids might be helpful.

The subtask failures involving the highest repetition times for operator 2 are shown in Table 2-5.

Table 2-5

High Failure (Repetition) Time Subtasks for Operator 2

Task Number	Failure Time*	Description
16	4183.20	Classify target
23	181.83	Search
2	178.03	Slew cursor
13	174.62	Slew cursor to measure bearing
6	154.55	Slew cursor
9	129.16	Measure harmonies

**Times are total across 100 iterations.*

The target classification subtask was suggested by the simulation to be the most salient in terms of contributing to time consumption because of subtask failure. This finding is concordant with the finding relative to failure frequency.

Peak Stress

An examination of the subtasks on which the highest stress occurs can also provide insight into the critical points of a scenario. The simulation induced peak stress points for operator 1 are presented in Table 2-6.

Table 2-6

Peak Stress Subtasks for Operator 1

Team Proficiency	Time Allowed (Seconds) 1380	1440	1500
.9	32,31*	32,31	-
1.0	33,32, 31,22	32,32,22	-
1.1	32,31	32,31,26,22	32
1.2	32,31	32,33,27,22	32,31

Subtasks on which peak stress occurred in 5 per cent of the iteration or more.

Peak stress for operator 1 generally was indicated to occur towards the conclusions of the scenario simulated, i.e., after target loss and during the attempt at target reacquisition. These data are in accordance with the prior suggestion relative to job aiding for this stage of the scenario. Subtasks 22 (note change in bearing rate), 26 (derive speed change) and 27 (recommend speed change) also indicated peak stress under the two shorter time allowances. These data are also in conformity with prior indications. In the 25 minute time allowance, the F= 0.9 and F= 1.1 operator teams evidenced no stress at all. Accordingly no peak stress is reported for these conditions.

Operator 2 indicated a similar peak stress pattern. The peak stress tasks for operator 2 are presented in Table 2-7.

Table 2-7

Peak Stress Subtasks for Operator 2

Team Proficiency	Time Allowed (Seconds) 1380	1440	1500
.9	24,23*	24,16	16
1.0	24,23	24,19,18,16	24,17
1.1	24.23	24,19,16	24,16
1.2	24,23	24,19,18,16	24,18,16

**Subtasks on which peak stress occurred in 5 per cent of the iterations or more.*

Subtasks 23 and 24, which seem to predominate in the Table 2-7 analysis are concerned with target reacquisition after target loss. This was the same scenario segment for which peak stress was identified for operator 1. Subtask 19 (report classification) was next most salient in this analysis and subtask 16 (classify target) followed.

Subtask 18 (report interfering target) and subtask 16 (notice target) also tended to be stress inductive during certain simulations. In summary, for operator 2 and for the scenario simulated, the target recognition tasks indicated the most stress along with subtasks and considerations concerned with the interfering target. These stress points seem reasonable and in accordance with logical expectancy.

Waiting Time

Within the scenario simulated, considerable operator time was spent in waiting for reports from a partner and for the ship to complete a maneuver. The percentage of mission time spent waiting for the F= 1.0 ("average") operator team is presented in Table 2-8.

Table 2-8

Waiting Time Percentage for Various Time Allowances

Operator	Time Allowed (Seconds) 1380	1440	1510
1	58%	56%	53%
2	78%	73%	72%

Roughly 55 per cent of the time of operator 1 was spent waiting and 45 per cent involved actual work. For operator 2, waiting time involved 75 per cent of the total. During this "waiting time" the crewman may be performing nonscheduled or nonessential subtasks such as monitoring displays. However, in the present simulation, it seems that the crew workload was low. This indication opens the possibility of one operator maning, at least from the point of view of the scenario simulated.

Discussion

The combined AN/SQS-26 and AN/SQR-XX sonar system was suggested by the computer simulation to be an effective and functional concept, at least for the scenario simulated.

The primary simulation results indicated a 76 per cent predicted average mission success when 24 minutes were allowed for completing all required operator actions. When the time allowed was decreased to 23 minutes, only 55 per cent success was indicated. Increasing the time allowed to 25 minutes yielded a 94 per cent predicted success rate.

Subtask failure frequency, subtask repetition time, and peak stress subtask analyses were in general conformity and suggested the most system debilitating subtasks to be those concerned with target acquisition after target loss, classification, target location on PNB, and cognitively oriented subtasks such as speed change derivation and intercept course derivation. Design emphasis in these areas may be indicated along with job aid provisions. Alternatively, these may represent areas for training emphasis. There is also the possibility that a "predictive" type of display, for use during target reacquisition, would exert a pronounced effect on total task success. Similarly, "computer guiding" during classification might be helpful.

The simulation results did not suggest that, for the scenario simulated, the operators are under high time pressure. These data, when viewed in conjunction with the Figure 1-2 time line analysis suggest that single operator manning (given appropriate equipment design) may be possible.

Certainly, only one scenario was simulated in the present analysis. Simulation of operator performance for other typical and atypical conditions may be indicated.

Summary and Conclusions

A computer simulation model was employed to simulate the acts of the operators of the combined AN/SQS-26 and AN/SQR-XX system as they perform the sequence cf subtasks involved in a complex scenario involving search, detection, track, loss of contact, and target reacquisition with interference from a secondary target. Simulations of the performance of "average," "above average," and "below average" teams was completed when various time quotas are allowed for completion of all "essential" subtasks. For the scenario simulated, the following conclusions seem indicated:

1. For "average" operators and in terms of the success criterion employed, a 76 per cent success rate was indicated or about a 25 per cent system degradation due to operator unreliability.

2. Time allowance seemed to exert a greater effect on success rate than simulated variation in operator proficiency.

3. The subtasks which seemed to contribute most to system unreliability as a function of operator unreliability were those subtasks concerned with target reacquisition after contact loss, classification, target location on PNB, and cognitively oriented subtasks such as speed change/course derivation. Design and/or training emphasis may be indicated in these areas.

4. At least for the scenario and subtask sequence included, a relatively low workload was indicated. The possibility of one operator manning remains open.

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APPENDIX B

Report on Application of 4 to 20 Man Model

HUMAN RELIABILITY IN A COMBINED SONAR SYSTEM

II. Human Reliability for the AN/SQS-26, LAMPS, and AN/SQR-19 System

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Contract N00024-76-C-6126

December 1976

ABSTRACT

A multiman human reliability simulation model was used to predict the operator performance in the combined AN/SQS -26, LAMPS, and AN/SQR-19 system. The simulated scenario involved prosecution of five targets, two of which were classified as threats, over a four hour period. For the selected scenario, a variety of simulations was completed. The various runs involved modifications of crew qualifications, work pace, and motivational conditions.

The results indicated that, regardless of crew qualifications or motivational level, reasonably high performance values can not be anticipated. Additional design emphasis on the operator/equipment interfaces and on the between human component information transfer was suggested as the method increasing predicted system performance level.

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CHAPTER I

INTRODUCTION AND MODEL DESCRIPTION

In 1975, the need for measurement of human reliability provoked the realization that a computer simulation model developed earlier at Applied Psychological Services possesses many of the necessary qualifications for preproduction estimation of human reliability in man/machine systems. The model considers the performance parameters which affect human reliability including human, equipment, and environmental considerations. Throughout this report the model is called the SW4-20 model after the model's developers (Siegel & Wolf) and the number of operators/maintainers of a system (between 4 and 20) which the model can simulate. The earlier developed SW4-20 model was accordingly elaborated to include the calculations necessary for providing the measures shown in Table 1. A number of other modifications were also added to the prior stochastic simulation model. These include but were not limited to:

1. Operator induced equipment failures
2. Equipment performance measures
3. Shift simulation capabilities
4. Increased consumable consideration including spare parts
5. Data summarization on equipment, human, and system reliability, availability, and mean time to repair

Description of SW4-20 Model

The model in its current form is basically a sequential processor with incorporated human, equipment, and environmental factors. To employ the model, the events to be performed by the system operators during a simulated mission are described through input data. The model's program organizes the events in sequence according to their prerequisite event and serial components. The sequencing allows branching for proportional inclusion of less likely tasks. Having organized the work, the model assigns appropriate crew members to each task and sequentially simulates the performance of the events by the simulated operators. After performance of all events scheduled has been simulated or the allowed time has elapsed, the mission is considered to be completed and output statistics reflecting performance quality are compiled. One simulation of a mission is called an iteration. Due to the stochastic nature of many of the model's features, reliable results require a number of iterations of a mission. These iteration results are averaged to yield final (run) results.

Table 1

Measures Added to SW4-20 Model

$$\text{HUMAN RELIABILITY} = \left(1 - \frac{\text{No. of failures}}{\text{Total attempts}}\right)$$

$$\text{HUMAN AVAILABILITY} = \left(1 - \frac{\text{Time lost or unmanned hours}}{\text{Total mission manhours}}\right)$$

$$\text{HUMAN MTTR} = \left(\frac{\text{Total time of second try}}{\text{No. of second try}}\right)$$

$$\text{EQUIPMENT RELIABILITY} = \left(1 - \frac{\text{No. of failures during mission}}{\text{No. of iterations}}\right)$$

$$\text{EQUIPMENT AVAILABILITY} = \left(\frac{\text{Equipment up time}}{\text{Equipment up time + down time}}\right)$$

$$\text{EQUIPMENT MTBF} = \left(\frac{\Sigma\ \text{times between failures}}{\text{No. of failures}}\right) = \left(\frac{\text{Mission time - down time}}{\text{No. of failures}}\right)$$

$$\text{EQUIPMENT MTTR} = \left(\frac{\text{Total EMTTR values over all iterations}}{\text{No. of iterations}}\right)$$

$$\text{SYSTEM RELIABILITY} = \left(1 - \frac{\text{No. of equipment failures} + \text{No. of second try successes}}{\text{No. of iterations}}\right)$$

$$\text{SYSTEM AVAILABILITY} = 1 - \left(\frac{\text{Equipment down time}}{\text{Mission time}}\right)\left(\frac{\text{Unmanned hours}}{\text{Mission time}}\right)$$

$$\text{SYSTEM MTTR} = \left(\frac{\Sigma\ \text{time for repairs} + \Sigma\ \text{time for second try successes}}{\text{No. of repairs} + \text{No. of Second try successes}}\right)$$

The model allows specification of complete output detail for every event performed, summary statistics on each iteration, overall run statistics, or any combination of these.

The details of the model (including model flow, variable descriptions, computational logic, and output descriptions) are found in Siegel, Wolf, and Lautman (1974) and in Siegel, Wolf, and Fischl (1969).

Logic Flow of SW4-20 Model

A summary flow chart of SW4-20 model is presented as Figure 1. The majority of the model input is entered in NAMELIST form. The NAMELIST form allows flexibility in the degree of precision of the input data and was thought to be most appropriate for this type of model. The second block of the input (Figure 1) shows the initialization of the simulated crew's proficiency, and motor capabilities parameters. The task and situational parameters which are to be represented during the simulation (including the emergencies, equipment failures, and illnesses) are also entered during this initialization.

Entry point "b" in Figure 1 leads to the factors which are considered prior to the simulation of each event or task processed during the simulated mission. The earliest time or starting time of an event is determined as a function of available crew, prerequisite task completion, and equipment availability. Whether or not to perform the event at all is determined on the basis of consumable availability, time available, task priority, and personnel available. The physical condition of the participating crew members in terms of time since last sleep and physical fatigue is also considered and evaluated before the actual task performance is simulated.

Having selected the tasks and the sequence of tasks whose performance is to be simulated this day, the model proceeds with the simulation of one day's performance of the crew. This is completed on a task-by-task basis. Then, the work of the next day to be simulated is organized and simulated. At the completion of the simulation of all days in the mission, the results are summarized. Additional simulations of the same mission are then performed in the same manner and the results of the individual simulations (iterations) are summarized into run results. A number of factors influence the performance of the simulated crew. These are summarized in Table 2 which presents the major variables considered by the model and the output provided. The use of each variable in the current simulation is shown in the right hand column of Table 2.

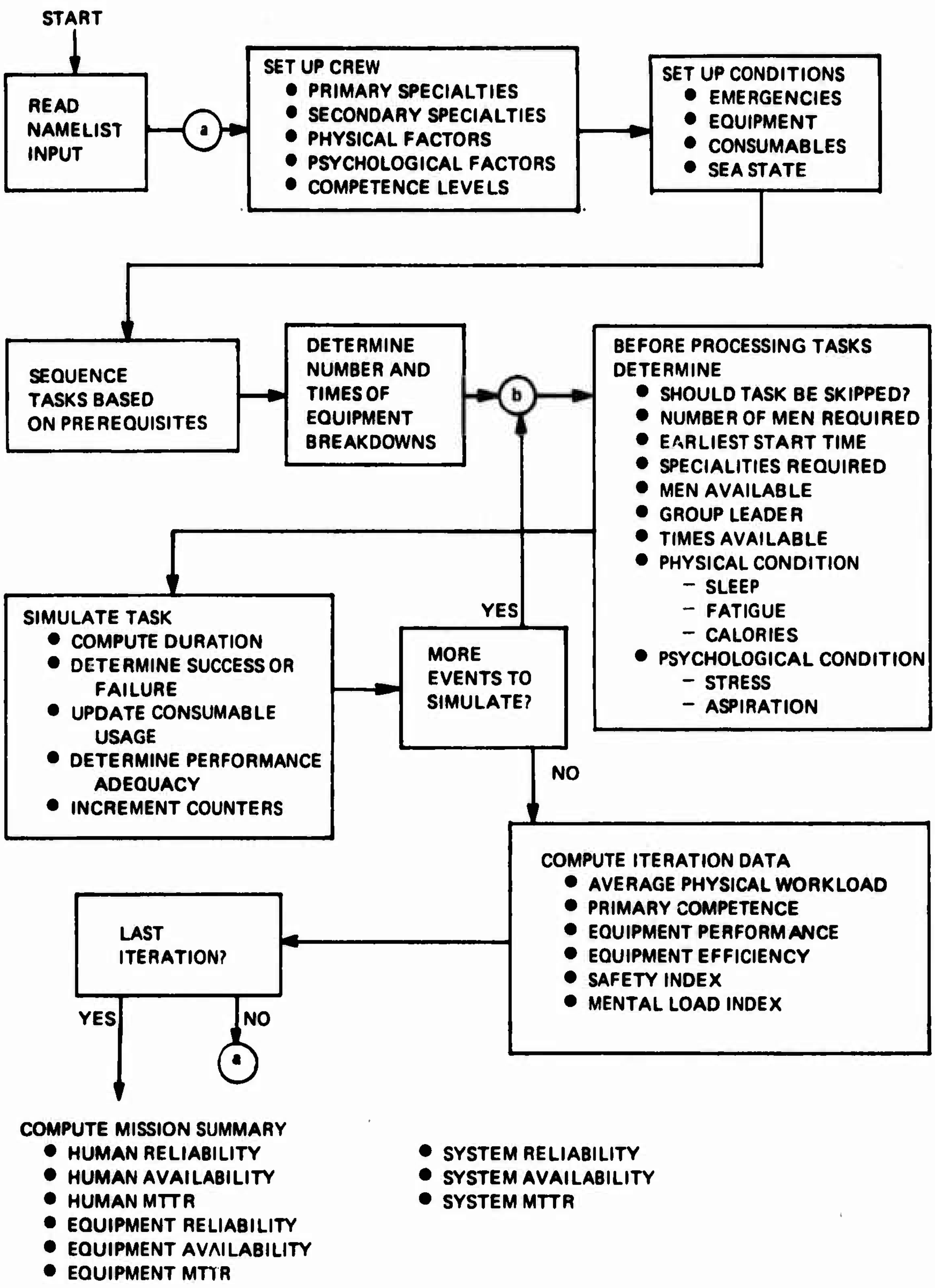

FIGURE 1. OVERVIEW OF FLOW IN SW4-20 STOCHASTIC SIMULATION MODEL.

Major SW4-20 Model Variables, Output, and Present Simulation Conditions

	VARIABLE		PRESENT SIMULATION CONDITIONS
PERSONNEL	Quantity	3-20 men groups group leader	4 men 1 group supervisor
	Categories/types	primary/secondary specialties 10 personnel specialties and cross training command echelon	4 primary specialties -supervisor, 36, LAMPS, 19 No cross training
	Goals	aspiration leader's expectation performance adequacy	normal, high, and low normal, high, and low
	Physical	physical workload motion sickness hazard (safety index) sleep physical incapability (sickness) physical workload	no physical incapacitation minimum to none low rested crews none minimum
	Performance Attributes	competence fatigue pace stress and stress threshold mental load unmanned station hours	complete and average no fatigue average and above average average high mental load
MISSION	Composition	200 event per day of 30 types	112 sequential tasks, 23 types
	Duration	hours to 30 days shifts	1 four hour shift
	Environment	sea state	sea state 1,2
	Elements (tasks)	essentiality types (scheduled, emergency, repair)	all tasks essential Repair and emergency events included
		precedence (task and time)	task and time prerequisites
		performance time fixed and variable event times	variable event times only
		touch up or repeat completion time limit	touchups and repeats allowed time limits whenever appropriate
EQUIPMENT	Quantity	30 types	3 types - 3 consoles
	Capability	failure and generation of repairs operator initiated failures	repairs to 3 consoles
	Performance/ Status	failure rates up time down time performance level consumables levels	failure rates included no consumables used
OUTPUT MEASUREMENTS	Mission Effectiveness	system reliability level	evaluated
		system performance level equipment performance efficiency system global effectiveness level consumables balances equipment and human MTBF & MTTR	most evaluated
	Time Utilization	success, idle, sleep, repair, no. of events, success, fail, ignore, primary, secondary	all evaluated
	Personnel	performance adequacy physical and mental load health and safety indices performance	evaluated included health and safety not evaluated considered
	Report Frequency	event, day, mission iterations, and run summary	full detail on all runs

Development and Validation of SW4-20 Simulation Model

The SW4-20 simulation model was first developed by Applied Psychological Services under contract with the Office of Naval Research (Siegel, Wolf, & Fischl, 1969). Since its original development, the model has been elaborated on and been the subject of a number of validational investigations. The most recent work on the model,including its extension into reliability, maintainability, and availability,have been supported by the Navy Sea Systems Command.

Reasonable and useful degrees of correspondence have been found between simulation output and actual Fleet data in a number of actual situations including Viet Nam river patrols (Siegel, Wolf, & Cosentino, 1971), trust territory reconnaissance by patrol gunboat class Navy ships (Siegel, Lautman, & Wolf, 1972) and sonar systems operating on DE1052 (Knox) class destroyer-escort vessels (Siegel, Wolf, & Williams, 1976).

CHAPTER II

THE PRESENT SIMULATION

The present report describes the methods and results of application of the SW4-20 model to the acts and behaviors of a sonar team operating the combined AN/SQS-26, LAMPS, AN/SQR-19 system during an attack situation which places a heavy load on the simulated sonar team.

The Mission Simulated

Within the present simulation, the system is assumed to be manned by four persons--a sonar supervisor and three operators. Each simulated operator is assigned to one console. The consoles are assumed to be organized into a complete sonar suite with information transferred from one console to another by manual means.

Own ship is assumed to be on a high speed transit and, over the course of the work simulated, five targets are processed. The sequence of events, as simulated, is shown in Figure 2. As indicated in Figure 2, a first target (target A) is detected 15 minutes into the scenario (t + 15) at which time it is processed. At t + 22, a second target (target B) is detected. Both targets are lost as they leave the second convergent zone (60,000 yards). At t + 58 and t + 85, target C and D are respectively detected and processed. At t + 107 target A enters the first convergent zone and is reacquired at t + 111. Target D enters the first convergent zone and is detected and processed starting at t + 135. At t + 150, a fifth target is detected (target E) in the second convergent zone and target B is shortly thereafter reacquired in the first convergent zone. At t + 185, target C is reacquired in the first convergent zone, and the decision is reached to attack target C. The scenario ends with the localization (and attack) of target C.

A major portion of the sonar team's activities is repeated for each target. The sequence is always initiated with target detection by the SQR-19 operator. The initial detection is assumed to require approximately five minutes with a standard deviation of two minutes. Following the initial contact, the LAMPS console operator switches to beam mode and then enters the target bearing and range data on the situation summary report. At this point, the supervisor, who has been observing the SQR-19 and the LAMPS operator actions, decides whether or not to classify the target, and whether the SQS-26 operator should be ordered to slew and search the first convergent zone. In the nominal case, it is assumed that the SQS-26 operator

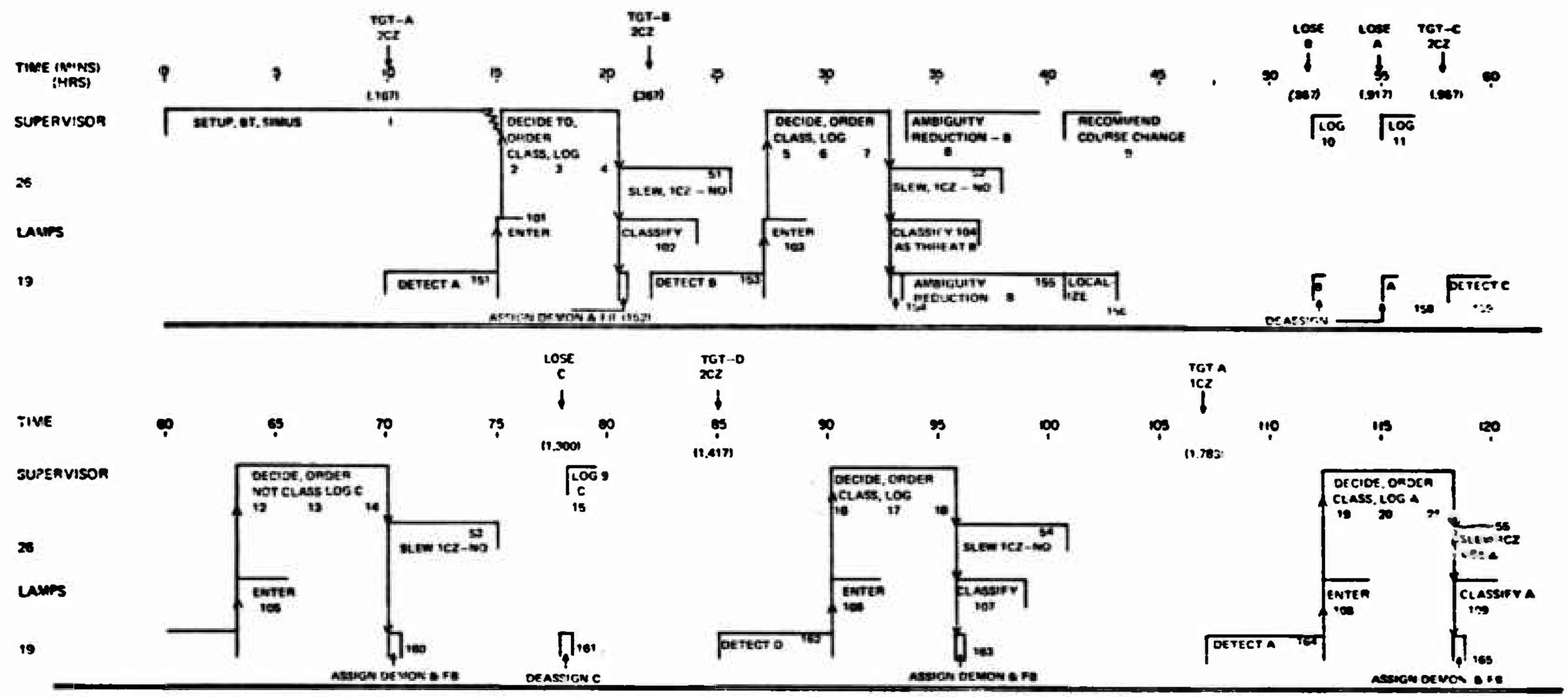

FIGURE 2. TIME LINE OF EVENT FLOW IN SIMULATED MISSION.

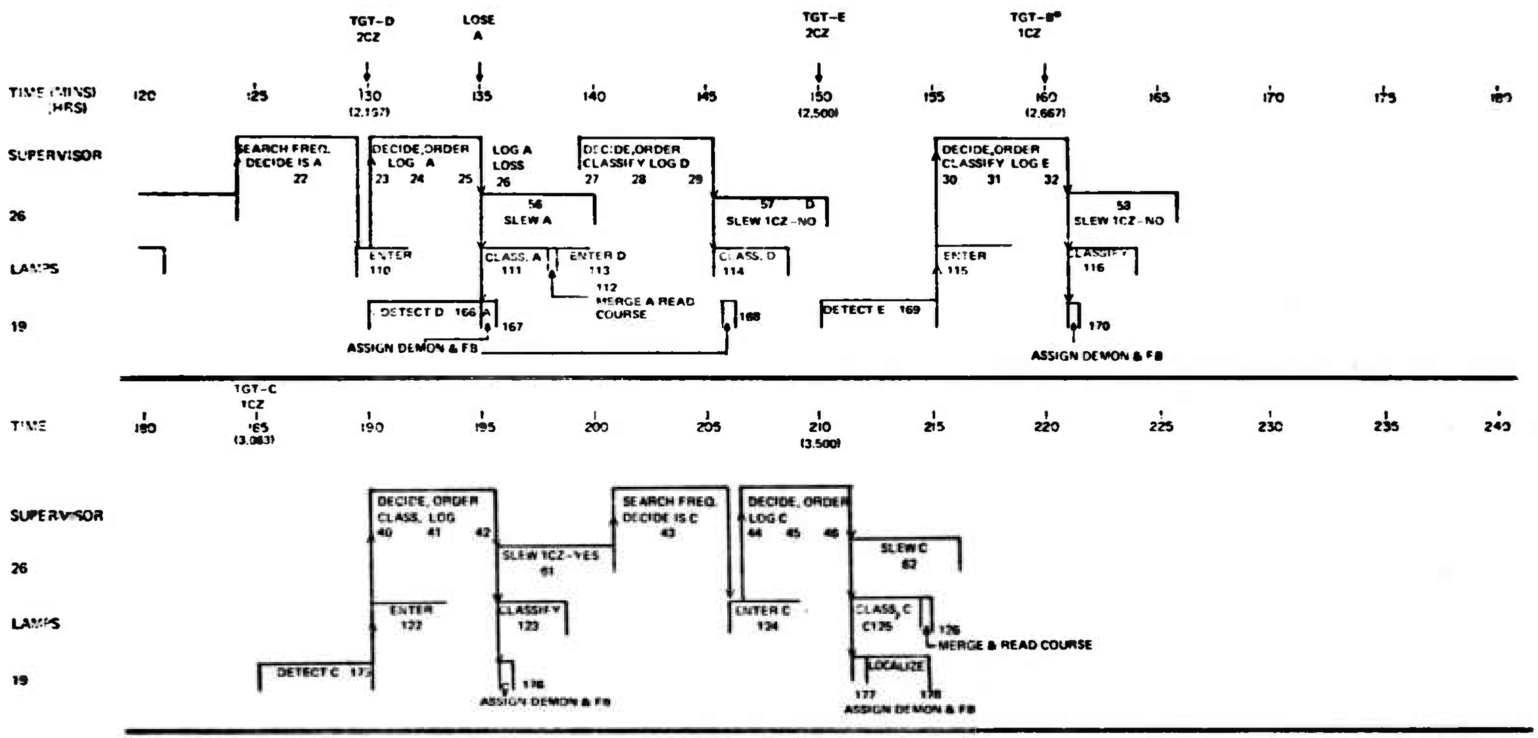

FIGURE 2 (Cont.)

* NOTE: TARGET B REACQUISITION IS NOT SHOWN ON THE MAIN TIME LINE DUE TO INTERFERENCE WITH E. IN FACT, TARGET E WOULD BE IGNORED WHEN THREAT B REAPPEARS.

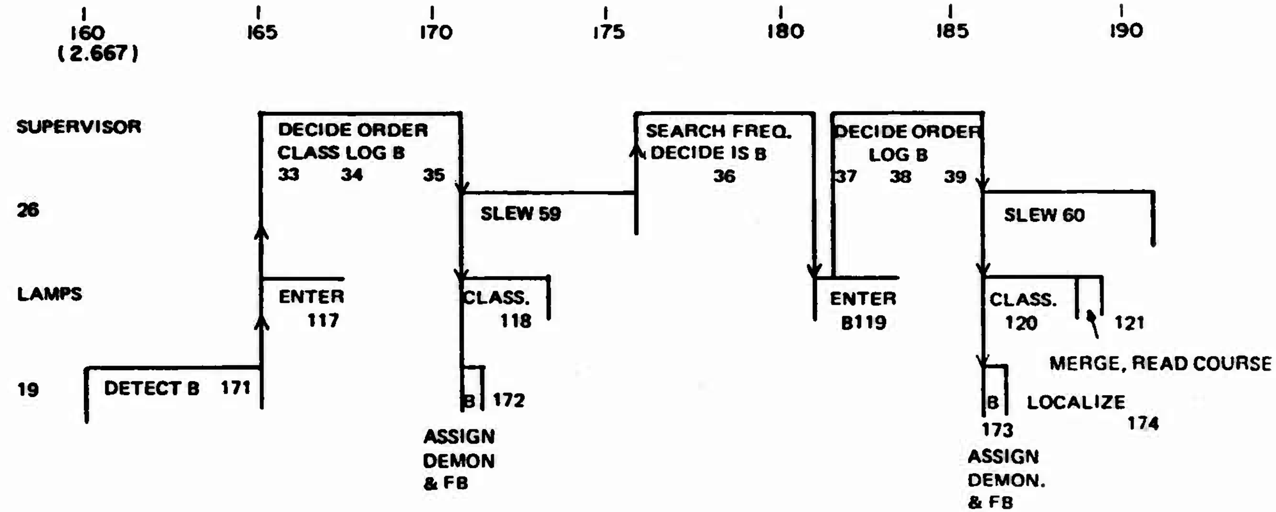

FIGURE 2. (Cont.)

will be ordered to slew and he will begin to do so. The LAMPS console operator is assumed, at this time, to begin to classify the target and the SQR-19 operator is assumed to assign DEMON and the fine bearing cursor. The supervisor will at this time log the target contact data.

The preceding activities describe the procedures assumed during the nominal target detection and classification where the target has not reached the first convergent zone or been classified as a threat.

In the case of a target found to be in the first convergent zone, the spectral characteristics of the target are assumed to be used by the supervisor to attempt to identify which, if any, of any previously identified targets is involved or whether a new target is involved. If no new target is involved, the supervisor then orders the LAMPS operator to merge the two targets. The LAMPS operator, when so ordered, is assumed to set up for data entry and to then instruct the computer to merge the two targets. Having merged the targets, the course and speed of the merged target is read directly and necessary course changes to avoid or to intercept the target are determined.

Deassignment is assumed to occur when a target passes out of a convergent zone. When this occurs, the SQR-19 operator manually deassigns the cursor. Similarly, the supervisor makes a log entry indicating the time and location at which the target exited the zone.

Table 3 presents the number of different events (tasks) assigned to each operator and the supervisor in the simulation. The supervisor had the heaviest number of tasks (46 tasks) while the SQS-26 operator had the least (12 tasks). Intervals (divisible by 50) between the assigned tasks and the next task number were left unassigned in order to allow easier identification between operators.

Table 3

Sequenced Event Allocation

OPERATOR	TASK NUMBERS	NUMBER OF TASKS
Supervisor	1-46	46
AN/SQS-26 Operator	51-62	12
LAMPS Operator	101-126	26
AN/SQR-19 Operator	151-178	28
TOTAL		112

Event Type Data

For the purposes of the present simulation, 23 event types were identified and quantified. The resulting data as organized for model input are shown in Table 4. The column headings identify the data type. Three lines are used to describe each event type. The first line gives the type number, an identifier (i.e., prose description), the average and standard deviation of the duration (in hours) of the event, the class (a model bookkeeping identifier), the number of pieces of equipment required for performing the event, and which equipment. For example, event type 1 is concerned with "WATCH SET UP," has a mean duration of .333 hours, is of class 1, and involves three units of equipment: equipments 1, 2, and 3 which are the three separate consoles.

The second data row for each event type contains the event essentially, the mental load imposed by the event on the operators, the event kind, the training code, the events hazard level, the number of men required for performing the event, and the consumable expenditure rate in units per hour. In the case of event type 1, there is an essentiality of 100 (maximum), a mental load of 7 (scaled 0 to 9), an event kind of 2 (kind 1 is end time fixed while kind 2 is variable end time, according to circumstances), a training code of 1 (2 is a training event while 1 is normal event), and a hazard level of 2 (code: 1-3= low, 4-6= medium, 7-9= heavy). Up to 10 types of men may be specified as required for performing different events. In event type 1, only one of man type 1 is required. No consumables are considered to be used in this event type.

Table 4

Event Type Data

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EVENT TYPE DATA

TYPE / ESSEN-TIALITY	IDENTIFIER / MENTAL LOAD	EVENT KIND	TRAIN	HAZARD CODE	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
TYPE	IDENTIFIER														DURATION AVG.	SIGMA		CLASS		NUMBER OF EQUIPS. REQD.		EQUIPMENT NUMBERS REQD 1 2 3 4 5 6		
ESSEN-TIALITY	MENTAL LOAD	EVENT KIND	TRAIN	HAZARD CODE	NUMBER OF MEN REQUIRED										CONSUMABLE EXPENDITURE RATE (UNITS/HR.)									
					CONSUMABLE EXPENDITURE RATE (UNITS)										EXPECTED ENERGY CONSUMPTION									
1	WATCH SET UP														0.333	0.111		1		3		1 2 3 0 0 0		
100	7.	2	1	2.	1	0	0	0	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
2	DETECT TARGET														0.083	0.033		2		1		3 0 0 0 0 0		
100	4.	2	1	2.	0	0	0	1	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
3	SWITCH BEAM + ENTER ETAS DATA														0.052	0.034		3		1		2 0 0 0 0 0		
100	4.	2	1	2.	0	0	1	0	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
4	SUPERVISE DECISION,COMMAND OR LOG														0.033	0.017		4		0		0 0 0 0 0 0		
100	5.	2	1	2.	1	0	0	0	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
5	SLEW TO BEARING - LOOK FOR TARGET														0.083	0.007		5		1		1 0 0 0 0 0		
100	4.	2	1	2.	0	1	0	0	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
6	CLASSIFY ETAS TARGET														0.050	0.033		6		1		2 0 0 0 0 0		
100	8.	2	1	2.	0	0	1	0	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
7	ASSIGN DEMON + FJ OR DEASSIGN														0.003	0.001		7		1		3 0 0 0 0 0		
100	4.	2	1	2.	0	0	0	1	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
8	AMBIGUITY REDUCTION														0.133	0.033		8		1		3 0 0 0 0 0		
100	8.	2	1	2.	1	0	0	1	0	0	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
					0	0	0	0	0	0	0	0	0	0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

```
  9   COMMUNICATE RECOMMENDED COURSE CHANGE                                0.006  0.001    9           0           0 0 0 0 0 0
100     6.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 10   LOCALIZE                                                             0.044  0.016   10           1           5 0 0 0 0 0
100     5.      2      1      2.     0   0   0   1   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 11   SEARCH FREQUENCY LOGS, DECIDE REACQUIRE                              0.083  0.033   11           0           0 0 0 0 0 0
100     5.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 12   MERGE TARGETS                                                        0.004  0.002   12           1           2 0 0 0 0 0
100     4.      2      1      2.     0   0   1   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 13   SWITCH BEAM - ENTER ETAS DATA                                        0.052  0.034    3           1           2 0 0 0 0 0
 70     4.      2      1      2.     0   0   1   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 14   SUPERVISOR DECISION COMMAND OR LOG                                   0.033  0.017    4           0           0 0 0 0 0 0
 70     5.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 15   SLEW TO BEARING - LOOK FOR TARGET                                    0.085  0.007    5           1           1 0 0 0 0 0
 70     4.      2      1      2.     0   1   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 16   CLASSIFY ETAS TARGET                                                 0.050  0.033    6           1           2 0 0 0 0 0
 70     5.      2      1      2.     0   0   1   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 17   ASSIGN DEMON + F3 OR DEASSIGN                                        0.003  0.001    7           1           3 0 0 0 0 0
 70     4.      2      1      2.     0   0   0   1   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  100.  100.  100.  100.  100.  100.  100.  100.  100.  100.

 18   REPAIR 26 - CONSOLE                                                  2.000  0.600   13           1           1 0 0 0 0 0
100     5.      2      1      2.     1   1   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.

 19   REPAIR LAMPS CONSOLE                                                 0.330  0.110   14           1           2 0 0 0 0 0
100     5.      2      1      2.     1   0   1   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.

 20   REPAIR 19 - CONSOLE                                                  0.670  0.220   15           1           3 0 0 0 0 0
100     5.      2      1      2.     1   0   0   1   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.

 21   REPAIR COMPLETION AND CHECKOUT - CONSOLE 1                           0.010  0.003   16           1           1 0 0 0 0 0
100     5.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.

 22   REPAIR COMPLETION AND CHECKOUT - CONSOLE 2                           0.010  0.003   17           1           2 0 0 0 0 0
```



```
100     5.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.

 23   REPAIR COMPLETION AND CHECKOUT - CONSOLE 3                           0.010  0.003   18           1           3 0 0 0 0 0
100     5.      2      1      2.     1   0   0   0   0   0   0   0   0   0    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
                                     0   0   0   0   0   0   0   0   0   0  200.  200.  200.  200.  200.  200.  200.  200.  200.  200.
```

The third line of event type data (Table 4) contains the consumable expenditure rate in units and the expected energy consumption by each man type during event performance. In the current simulation no consumables were assumed to be used and the energy expenditure rate was set at 100 calories per hour.

Event types 1 to 17 in Table 4 are operational and target processing tasks while event types 18 to 23 are repair events.

Equipment and Repair Event Data

Table 5 presents the equipment repair input data used in the simulation. Repair data were inserted for three pieces of equipment, i.e., the SQS-26, LAMPS, and SQR-19 consoles. The first column for each event identifies the event type to be used (as described previously) in the event type data. Other critical information included in this section includes the equipment reliability (e.g., mean time between failures of 31.2 days for equipment number 1) and the maximum repair time ("duration target" of 4.00). The data are used before each iteration to determine stochastically the occurrence or non occurrence of a failure and when it will occur. The equipment reliability values were taken from system design requirements.

Table 5

Repair Event Input Data

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EQUIPMENT AND REPAIR EVENT DATA

EQUIP TYPE	DESCRIPTION	-CONSUM. (UNITS/HR)	THRESHOLD SET- (UNITS)	RELIABILITY (DAYS/FAIL)	TIME UNAVAIL	EVENTS/ FAMILY
1	CONSOLE 1, - NO.26	0	0	31.200	0.	2

EVENT TYPE	NEXT EVENT 1	NEXT EVENT 2	NEXT EVENT 3	PROBABILITY 1	PROBABILITY 2	PROBABILITY 3	REPEAT/ TOUCHUP	DATA CHG NO 1	DATA CHG NO 2	DATA CHG NO 3	DATA CHANGE VALUE 1	DATA CHANGE VALUE 2	DATA CHANGE VALUE 3	PREC. EVENT	FAMILY INDIC.	FAMILY NUMBER	DURATION TARGET	EVENT NUMBER IN FAMILY	EVENT NUMBER COMPUTER
18	202	200	200	1.00	0.	0.	2	0	0	0	0.	0.	0.	0	1	1	4.00	1	201
21	200	200	200	1.00	0.	0.	2	0	0	0	0.	0.	0.	201	2	1	0.01	2	202

EQUIP TYPE	DESCRIPTION	-CONSUM. (UNITS/HR)	THRESHOLD SET- (UNITS)	RELIABILITY (DAYS/FAIL)	TIME UNAVAIL	EVENTS/ FAMILY
2	CONSOLE 2, LAMPS	0	0	8.330	0.	2

EVENT TYPE	NEXT EVENT 1	NEXT EVENT 2	NEXT EVENT 3	PROBABILITY 1	PROBABILITY 2	PROBABILITY 3	REPEAT/ TOUCHUP	DATA CHG NO 1	DATA CHG NO 2	DATA CHG NO 3	DATA CHANGE VALUE 1	DATA CHANGE VALUE 2	DATA CHANGE VALUE 3	PREC. EVENT	FAMILY INDIC.	FAMILY NUMBER	DURATION TARGET	EVENT NUMBER IN FAMILY	EVENT NUMBER COMPUTER
19	214	212	212	1.00	0.	0.	2	0	0	0	0.	0.	0.	0	1	2	0.67	1	213
22	212	212	212	1.00	0.	0.	2	0	0	0	0.	0.	0.	213	2	2	0.01	2	214

EQUIP TYPE	DESCRIPTION	-CONSUM. (UNITS/HR)	THRESHOLD SET- (UNITS)	RELIABILITY (DAYS/FAIL)	TIME UNAVAIL	EVENTS/ FAMILY
3	CONSOLE 3, - NO.19	0	0	18.330	0.	2

EVENT TYPE	NEXT EVENT 1	NEXT EVENT 2	NEXT EVENT 3	PROBABILITY 1	PROBABILITY 2	PROBABILITY 3	REPEAT/ TOUCHUP	DATA CHG NO 1	DATA CHG NO 2	DATA CHG NO 3	DATA CHANGE VALUE 1	DATA CHANGE VALUE 2	DATA CHANGE VALUE 3	PREC. EVENT	FAMILY INDIC.	FAMILY NUMBER	DURATION TARGET	EVENT NUMBER IN FAMILY	EVENT NUMBER COMPUTER
20	226	224	224	1.00	0.	0.	2	0	0	0	0.	0.	0.	0	1	3	1.00	1	225
23	224	224	224	1.00	0.	0.	2	0	0	0	0.	0.	0.	225	2	3	0.01	2	226

Scheduled Event Data

The sequence of events shown in Figure 2, is presented in the form required for computer input in Appendix A. The types referred to in column 2 of Appendix A refer to the event types described earlier. The next two columns describe consumable data. No consumable use was involved in this simulation. The next six columns of Appendix A refer to the task to be performed after the listed task. For example, in the case of event 1, the next event to be performed is event 151. Reference to Figure 2 shows that this is the "DETECT A" event performed by the SQR-19 operator.

Since sequenced event 151 always follows event number 1, all three possible entries are filled with the number 151. The probability of performing each next event follows the event. In this case, a probability of 1.0 (certainty) is used following the first probability. Since the events are always considered in the order 1, 2, then 3, the first probability must is indicated as 1.0. Following the next event data, any necessary precedent event (event which must be completed before present event can start) be indicated. While event 1 has no precedent event, event 2 has a precedent of event 101. This means that event number 101 must be completed before event number 2 can be performed. Following the precedent data, the temporal requirements are given. The first number, identified as "START TIME," indicates the earliest time at which the event may be started. In the case of event 1, the entry is zero. This indicates that event 1 may start at the start of the simulation. In the case of event 2, an earliest starting time of .17 hours is specified. This means that event 2 may not start, or must be delayed until .17 hours into the mission. The "TIME LIMIT" number following the start time is the time by which the event must be finished. If the task is not completed before this time, it is terminated at the time limit. If the event was not started before the time limit, the event is ignored. The final entry shown in Appendix A is the "REPEAT/TOUCHUP CODE." The key to this code is shown in the column headings. An entry of 1 indicates an event which is repeated in full if it is failed by the simulated operator(s). An entry of 2 indicates an event which requires only a touchup (.1 of normal event time) if it is failed. A 3 indicates an event which either allows or requires no further action when it is failed.

Basic Parameters of Current Simulation

Table 6 presents the baseline parameters used in the present evaluation. The values shown in Table 5 were held constant across all runs except where specifically indicated in subsequent sections of this report. The nominal pace, or speed, of all crewman was set at 1.00 (average); the nominal stress threshold was set at 2.3 in the present evaluation (about average); the nominal level of aspiration was 1.00 (a value indicating a desire to perform in accordance with proficiency) and so on. All of these values are used as means and actual values used in any specific simulation run are stochastically determined within the logic of the SW4-20 model.

The variables in the second group (starting with "HOURS SINCE LAST SLEEP" were used as the initial values in the simulation. Note that the amount of working time allowed was four hours.

All consumable information, initial and usage rate, were set at zero. Accordingly, consumables were not involved in the present validation.

Since seasickness was not a variable of interest in this simulation, the probabilities of sea state were set to a value of 2 to produce a continuous mild sea state.

Personnel characteristics included a mean body weight of 170 pounds with a standard deviation of 15 pounds. All personnel were set to be 100 per cent fully qualified in their primary specialty and in their secondary specialty. The final values of interest in this section are the "CREW ASSIGNMENT TO SHIFTS BY MAN." All crew members were assigned to the first shift in the present simulations since only one shift (watch) was simulated.

These basic parameters were held constant while other parameters were varied across simulation runs to allow test of the effects of varying certain parameters on system performance.

Table 6

Baseline (Nominal) Parameters in Present Simulation

INTEGRATED 26, 19, LAMPS SYSTEM 11/08/76 PAGE 1

PARAMETER INPUTS FOR THIS 1 DAY'(4.0 HOURS) RUN OF 5 MISSION ITERATIONS
ENTITLED INTEGRATED 26, 19, LAMPS SYSTEM

- - - - AVERAGE CREW DATA - - - -

PACE	STRESS THRESHOLD	ASPIR-ATION	CALORIES REQD PER DAY	POWER RATE CALS/HR.
1.00	2.30	1.00	2400.	200.0

HOURS SINCE LAST SLEEP	CATNAP LENGTH (HRS)	MAXIMUM SLEEP PER DAY	--WORK LIMITS(HRS)-- NO MORE ASSIGNMENTS	NO MORE WORK	-------THRESHOLDS------ FATIGUE	ESSENTIALITY	------------CONSTANTS-------------------- UNMANNED STATION HRS	LEADERS EXPECTATION	PHYSICAL CAPABILITY	STRESS
1.0	0.5	8.0	4.0	4.0	0.25	50	0.50	0.95	0.95	0.50

	SET	1	2	3	4	5	NUMBER 6	7	8	9	10
INITIAL VALUE OF CONSUMABLES (UNITS)		1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
INITIAL VALUE OF CONSUMABLES (UNITS/HR)		1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
CONSUMABLE THRESHOLDS (UNITS)	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	10	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
CONSUMABLE THRESHOLDS (UNITS/HR)	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	10	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
CUMMULATIVE PROBABILITY OF SEA STATES		0.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
AVERAGE EQUIPMENT INTERMITTANT RELIABILITY		0.	0.	0.	0.						
OUTPUT RECORDING OPTIONS		1	1	1	1	1	1	1			

PERSONNEL DATA

- BODY WEIGHT - MEAN	SIGMA	SPECIALTY	FRACTION OF CREW QUALIFIED FULLY	MINIMALLY	UN
170.0	15.0	PRIMARY	1.00	0.	0.
		SECONDARY	1.00	0.	0.

LEVEL	NUMBER OF MEN IN CREW BY TYPE 1	2	3	4	5	6	7	8	9	10
1	1	0	0	0	0	0	0	0	0	0
2	0	1	1	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

CUMULATIVE CROSS TRAINING PROBABILITIES

MAN TYPE	1	2	3	4	5	6	7	8	9	10
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	0.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	0.	0.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	0.	0.	0.	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

CREW ASSIGNMENT TO SHIFTS BY MAN

SHIFT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(1 - ASSIGNED 0 - UNASSIGNED)

--PHYSICAL CAPABILITY AVERAGES-- MAN DAYS PER INCIDENCE	DURATION	PHYSICAL CAPABILITY CONSTANT
100.00	0.	2.00

Parameters Varied

The parameters varied in the simulation were: pace, aspiration, leader expectation, and per cent qualified. Table 7 lists the levels of these variables which were used in various simulation runs. In the cases of pace and aspiration, two additional levels were selected to allow consideration of the effect of additional training and/or heightened motivation on mission performance.

In the case of leader expectation, both higher and lower levels of expectation were employed to determine the effect supervisor performance demand on crew performance. Here, a value of 1.0 indicates that the simulated supervisor expects the crew to perform to the level of their present capability.

In the baseline condition, all men were fully qualified in their specialty. One additional run was completed with a lower percentage qualified--80 per cent fully qualified and 20 per cent marginally qualified--to depict the conditions which might sometime be found aboard ship.

Table 7

Simulation Parameters Varied in Each Run

RUN NO.	CONDITIONS CHANGED
1	None (Baseline)*
2	PACE= .80
3	PACE= .90
4	ASPIRATION= .90
5	ASPIRATION= .95
6	LEADER'S EXPECTATIONS= .85
7	LEADER'S EXPECTATIONS= 1.05
8	80 per cent qualified in specialty 20 per cent qualified in specialty

**Unless otherwise specified:*

PACE= 1.00
ASPIRATION= 1.00
LEADER'S EXPECTATIONS= .95
100 per cent fully qualified in specialty

CHAPTER III

RESULTS

The results of the computer simulation of the mission described in Chapter II are presented relative to a variety of the output measures yielded by the SW4-20 model.

Human Reliability

Human reliability is defined within the model as a function of the number of failures of events by the simulated team members. The results of the various simulation runs relative to this measure are presented in Table 8. The human reliability for the baseline conditions was .58. The obtained human reliability varied between .273 and .993. Generally, the human reliability values tend to be low. The exceptions are the crews with a low level of aspiration (a willingness to do poor work) and the crews with supervisors who possess a low performance expectation (a willingness to accept poor work). Increasing crew member working speed did not raise the obtained human reliability values to a value which might be considered acceptable for an advanced system and, when the team was 80 per cent qualified, the human reliability fell to .46.

The human reliability values were consistently lower than the corresponding model calculated equipment values. This result suggests that system reliability is negatively influenced by the crew member unreliability. This influence is reflected in the model calculated system reliability values given in the third column of Table 8. Generally, the system reliability values are at a unfavorable level and can probably most easily be moved upward by increasing the operator success rate.

A separate human reliability analysis was conducted, by operator, for the baseline run. The attempt of this analysis was to ascertain which operator(s) contributed most to the depressed human reliability values. The obtained human reliability values for the baseline run are presented by operator in Table 9. The supervisor who is involved in most of the decision making was indicated to possess the lowest human reliability. This indication suggests the need for decision aiding. While the decision events are not necessarily time consuming, failure of such events impedes performance. Prosecution of the events of the mission by other sonar system team members cannot take place until after the supervisor has made the appropriate decision.

Table 8

Human, Equipment, and System Reliability Under Various Simulated Conditions

SIMULATION RUN	Reliability HUMAN	EQUIPMENT	SYSTEM
Baseline*	.58	1.00	.58
Pace			
.8	.62	1.00	.62
.9	.61	.85	.46
1.0*	.58	1.00	.58
Aspiration			
.90	.84	.90	.74
.95	.61	.95	.60
1.00*	.58	1.00	.58
Leader Expectation			
.85	.99	1.00	.99
.95*	.58	1.00	.58
1.05	.27	.90	.17
% Fully Qualified			
80-20	.46	.90	.36
100-0*	.58	1.00	.58

*Baseline run

Table 9

Human Reliability for Each Simulated Operator (Baseline Run)

OPERATOR	HUMAN RELIABILITY
Supervisor	.49
SQS-26	.84
LAMPS	.58
SQR-19	.63

Individual analyses were also completed in terms of first trial success as a function of operator speed (pace) relative to three selected critical events. The events selected for detailed examination were: target detection, target classification, and target reacquisition. The operator paces used in these runs were 1.0 (average), .9 (faster than average), and .8 (much faster than average). A simulated sonar team with a pace of .8 works about 20 per cent faster than a team with a pace value of 1.0, other things being equal. Within the model, pace does not directly affect success probability. Rather, pace affects success indirectly, through the effect of pace on aspiration and stress. The results of these analyses are presented in Figures 3, 4, and 5.

Depressed human reliability values are similarly indicated for the events selected for individual analysis and the effect of the pace parameter was greater for these individual tasks than for the overall set of tasks. This would suggest that increased human reliability on the overall is required rather than emphasis on individual events.

The three points in each of Figures 3, 4, and 5 were used to calculate, by the least squares method, the theoretical ideal fit. The resulting line of best fit is shown. Also shown is the correlation (r) between operator pace and percentage of first trial successes. The correlation may be used as a rough quantification of the relationship. The equation describes the theoretical line of best fit where Y represents the ordinate and X represents the abscissa.

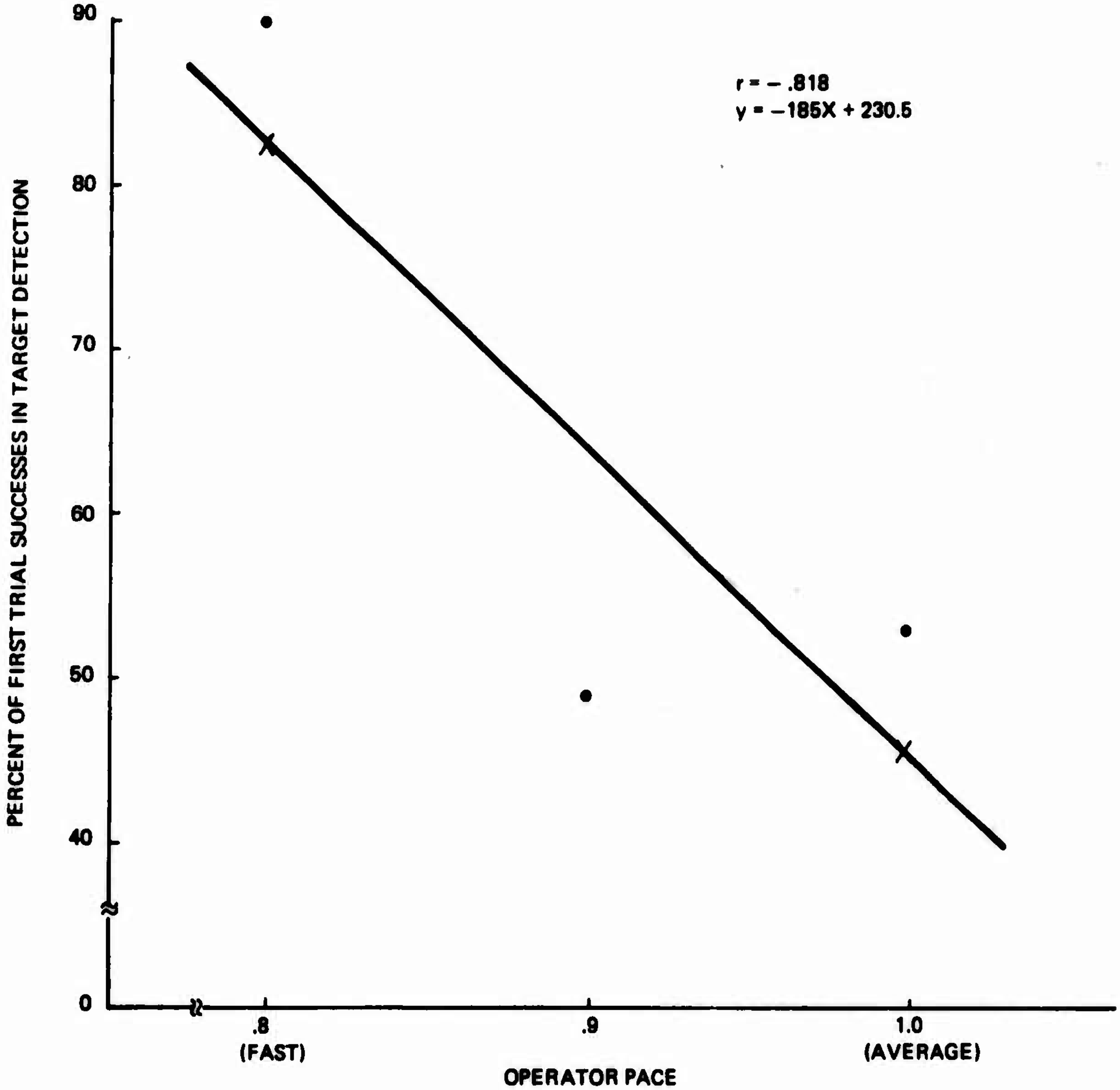

FIGURE 3. PERCENT OF FIRST TRIAL SUCCESSES ON TARGET DETECTION AS A FUNCTION OF OPERATOR PACE.

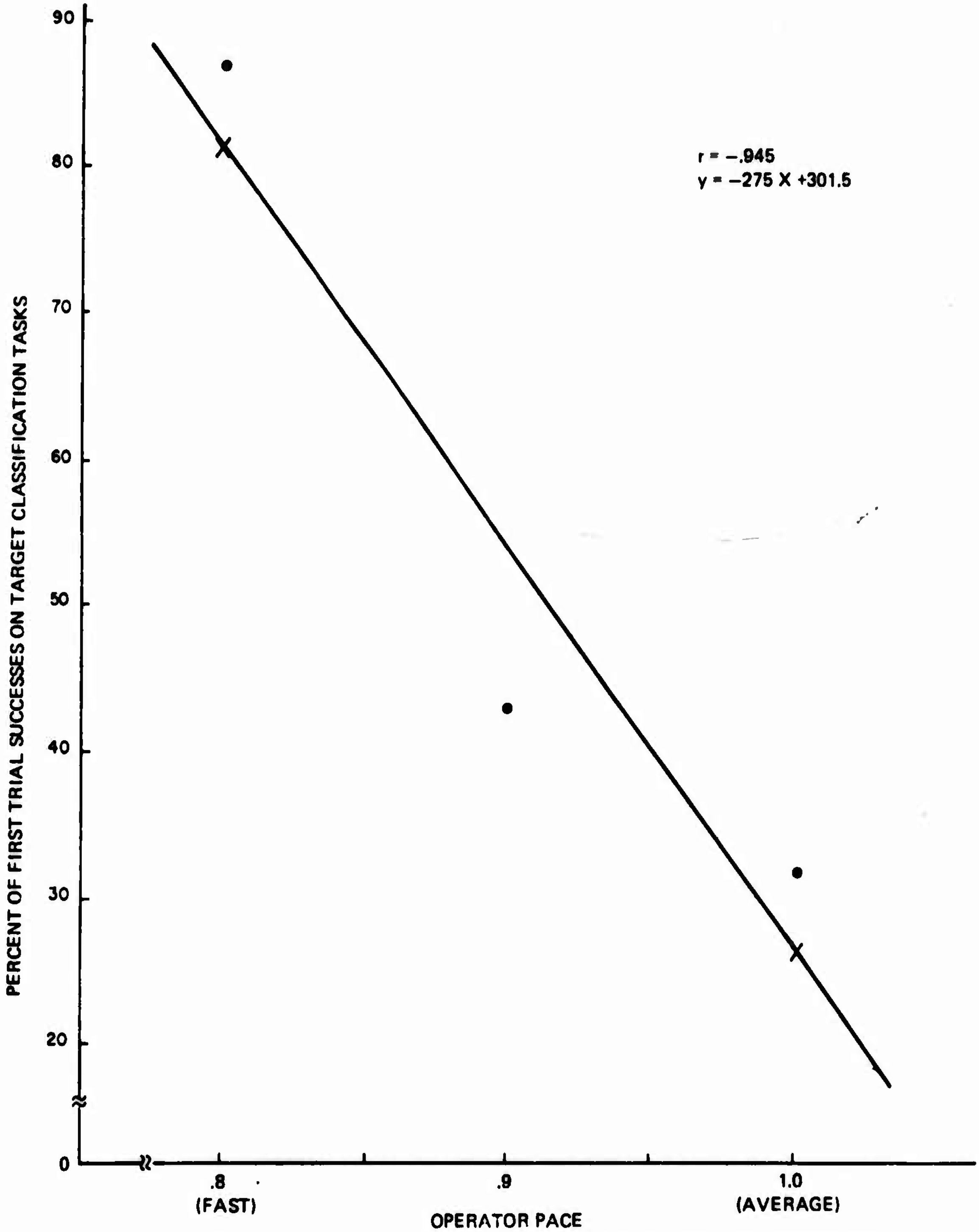

FIGURE 4. PERCENT OF FIRST TRIAL SUCCESSES ON TARGET CLASSIFICATION AS A FUNCTION OF OPERATOR PACE.

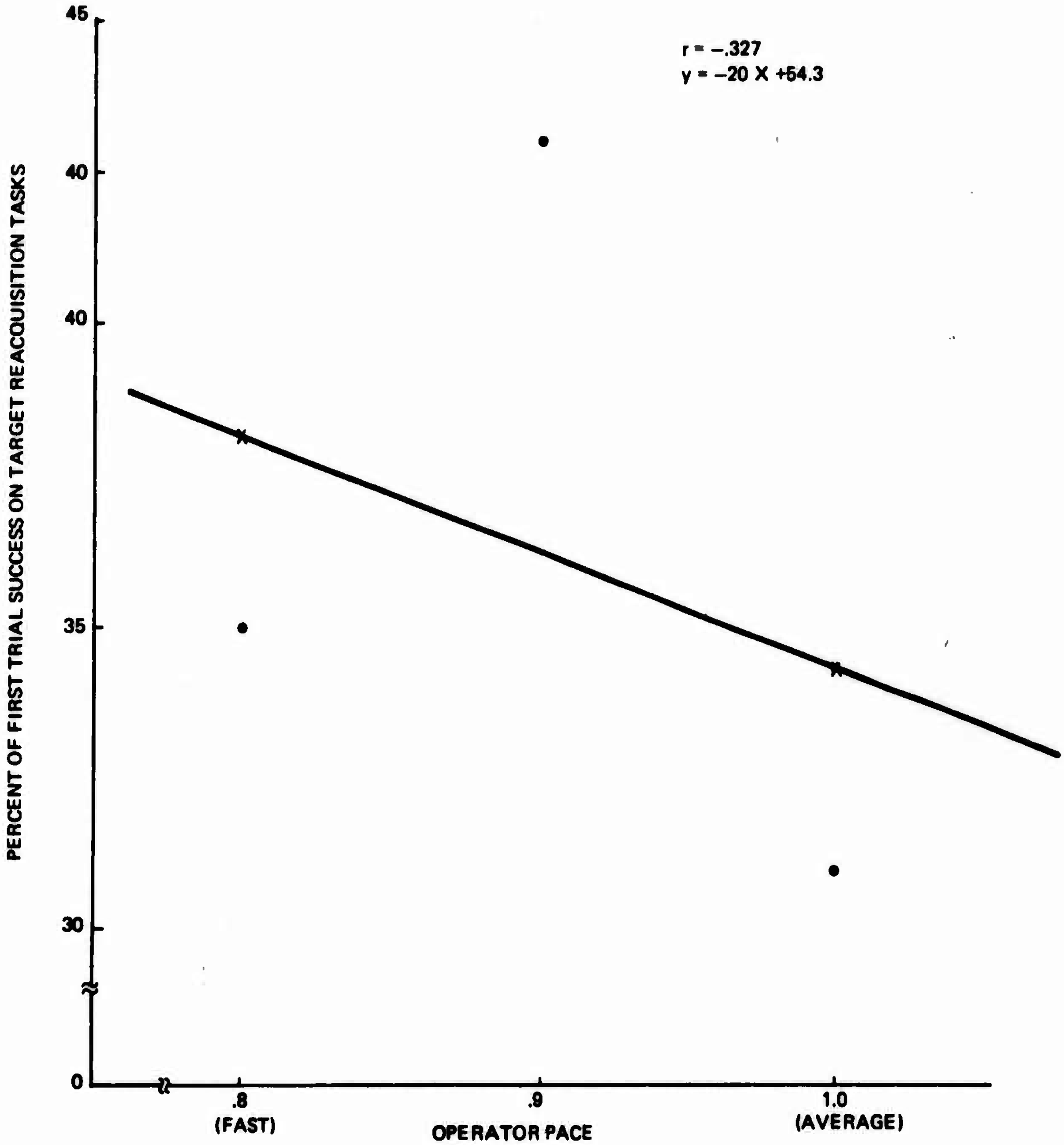

FIGURE 5. PERCENT OF FIRST TRIAL SUCCESSES ON TARGET REACQUISITION AS A FUNCTION OF OPERATOR PACE.

Human Availability

Within the SW4-20 model human availability is defined as a function of time that there is work to be performed but during which the work can not be accomplished because the crew members are performing other work (i.e., unavailable). The obtained availability values, as presented in Table 10, tend to be adequate although not high. This suggests that the manning level involved in the simulation was sufficient. When viewed in coordination with the prior reliability data, these results suggest combined SQS-26, LAMPS, SQR-19 system does not require more men but, rather, it requires easier performance.

The human availability indices tend to be lower than the equipment availability indices and, this finding suggests further support for the prior contention relative to the need for improved design from the operator point-of-view.

As for the human reliability analyses, the availability during the baseline run was calculated separately by operator. The results of this analysis are presented in Table 11.

As for the human reliability, the supervisor was indicated to represent the weakest human component in the system. The possibility exists that work aids/decision aids, as suggested above, would tend to lessen the decision load on the supervisor and make him more available. Alternatively, workload redistribution may be indicated. We also note that much of the communication load is carried by the supervisor. Possibly, a communications analysis would yield a basis for lightening the load on the supervisor. Certainly, a .44 availability value for the supervisor is unacceptably low and casts doubt on how well the combined SQR-26, LAMPS, SQS-19 system is integrated.

Table 10

Human and Equipment Availability Under Various Simulated Conditions

SIMULATION RUN	*HUMAN AVAILABILITY*	*EQUIPMENT AVAILABILITY*
Baseline*	.87	1.00
Pace		
.80	.91	1.00
.90	.79	.97
1.00*	.81	1.00
Aspiration		
.90	.81	.97
.95	.85	.99
1.00*	.81	1.00
Leader Expectation		
.85	.80	1.00
.95*	.81	1.00
1.05	.81	.98
% Fully Qualified		
80-20	.72	.98
100-0*	.81	1.00

**Baseline run*

Human Mean Time to Repair

Human mean time to repair reflects the amount of time consumed by an equipment operator or maintainer when he repeats or "touches up" a failed event. In view of the rather low obtained human reliability indices, one would anticipate that the predicted human mean time to repair values would be high. The human mean time to repair, as indicated by the computer model for the various conditions simulated, is presented in Table 12. For the baseline run, the human mean time to repair was indicated to be .06 hours or an average of 3.6 minutes for each failed event. In view of the rather high number of failed events, it becomes apparent that the total human availability would increase markedly if the design of the combined SQS-26, LAMPS, SQR-19 system was reconsidered so as to provide fewer human failures and, accordingly, less total human repair time.

Table 3 indicated a total of 112 events across all sonar team members for the simulated mission. Assuming: (1) an average of 28 events per team member (112 events/4 team members= 28 events per team member and (2) a human reliability of .58 (baseline results), then the simulation suggests that, on the average, each simulated team member failed 11.8 events (unreliability was 100 -.58= .42:.42 x 28= 11.76). With a human mean time to repair value of 3.6 minutes, this suggests that about 42.3 minutes (3.6 x 11.8= 42.3) of the four hour watch were spent in repeating or "touching up" failed events.

Table 12 also indicates that the human MTTR tended to be higher than the equipment MTTR. Accordingly, the result is that system MTTR is depressed.

Table 11

Human Availability for Each Simulated Operator (Baseline Run)

OPERATOR	*HUMAN AVAILABILITY*
Supervisor	.44
SQS-26	.86
LAMPS	.98
SQR-19	.93

Table 12

System, Human, and Equipment MTTR (Hours) under Various Simulated Conditions

	MTTR		
SIMULATION RUN	*HUMAN*	*EQUIPMENT*	*SYSTEM*
Baseline*	.06	.00	.06
Pace			
.80	.03	.00	.03
.90	.99	.01	.12
1.00*	.06	.00	.06
Aspiration			
.90	.05	.30	.07
.95	.04	.10	.05
1.00*	.06	.00	.06
Leader Expectation			
.85	-	.00	-
.95*	.06	.00	.06
1.05	-	.10	-
% Fully Qualified			
80-20	.27	.10	.12
100-0*	.06	.00	.06

**Baseline run*

The human MTTR value for each simulated team member is presented in Table 13. As indicated in Table 13 the SQS-26 operator seems to have contributed most to elevating the human mean time to repair values. Evidently, the events failed by the SQS-26 operator require long repetition and touchup times--even though the reliability and availability of this operator were not the lowest noted. The supervisor, who was previously indicated to possess depressed reliability and availability was indicated to possess the lowest human mean time to repair. This finding suggests that the problem involved in the supervisory events is not that the individual events are too time consuming. Rather, initial failure, due to task difficulty seems to be the problem.

Table 13

Human MTTR for Each Simulated Operator

OPERATOR	HUMAN MTTR
Supervisor	.11
SQS-26	.35
LAMPS	.14
SQR-19	.15

Performance Adequacy

The model also calculates a performance adequacy value which aims to provide an index of how well the simulated crew performs the various events of the mission. The obtained index can vary from zero to 100 and is based on the current competence of the crew member(s) performing each event, the stress level at the time of event performance, the current physical status of the crew member(s) performing the event, and the current aspiration level(s). The obtained overall performance adequacy for the baseline condition is presented in Table 14 along with the performance adequacy for each of three selected events. The values shown in Table 14 suggest moderate performance adequacy for each of the events selected for individual examination as well as for all of the tasks within the mission simulated. From the point of view of this analysis, the classification event would benefit most from increased design emphasis. The depressed performance adequacy values are a function of the time stress on the operators because the baseline condition included a 100 per cent fully qualified crew with an aspiration of 1.0 and there was little, if any, physical degradation in the simulation as performed. These values, when coupled with the human reliability and availability data, presented earlier, lend further support to contentions favoring a need for operability emphasis in the design of the combined SQS-26, LAMPS, SQR-19 systems.

Table 14

Overall Performance Adequacy and Performance Adequacy on Three Selected Events (Baseline Conditions)

EVENT	PERFORMANCE ADEQUACY
Overall	.82
Target Detection	.87
Classification	.73
Reacquisition	.77

Leader Expectation

The leader expectation focuses on the quality of performance demanded and acceptable to the simulated supervisor from the three simulated operators.

In the baseline simulation, an expectation of .95 was employed. This value was bracketed by leader expectations of .85 and 1.05 in other simulations.

As shown in Figures 6 and 7, performance adequacy and human reliability decreased as leader expectation increased. That is, only when leader expectation was low (i.e., willingness to accept inferior work) was performance adequacy judged reasonably good. As leader's expectations increased to the high quality work required by this mission, performance adequacy was shown to decrease.

Percentage of Crew Fully Qualified

Two levels of crew qualification were simulated. The baseline and all of the other runs except one, assumed that all personnel were 100 per cent fully qualified in their primary specialty, sonar operation and maintenance. A single run was made under the condition of 80 per cent of the crew fully qualified and 20 per cent minimally qualified.

Figure 8 presents the resulting difference, as indicated by the simulation, between the two qualification levels in overall percentage of first trial success. Figure 8 shows a 41 per cent drop in the mean number of first trial successes as a result of reducing the qualification level. Similarly, Figure 9 indicates that the mean percentage of tasks failed increased as the qualification index was lowered. The overall trends of human reliability, as shown in Figure 10 and 11, were also indicated by the simulation model to suffer decrement when the qualification level was reduced. These data suggest that performance on the combined SQS-26, LAMPS, SQR-19 system hinges on a well trained crew. A discussion of the ability of the Training Command to meet stringent training requirements is beyond the scope of the present report, However, it seems that this training requirement should be held in mind relative to the design of the system in question.

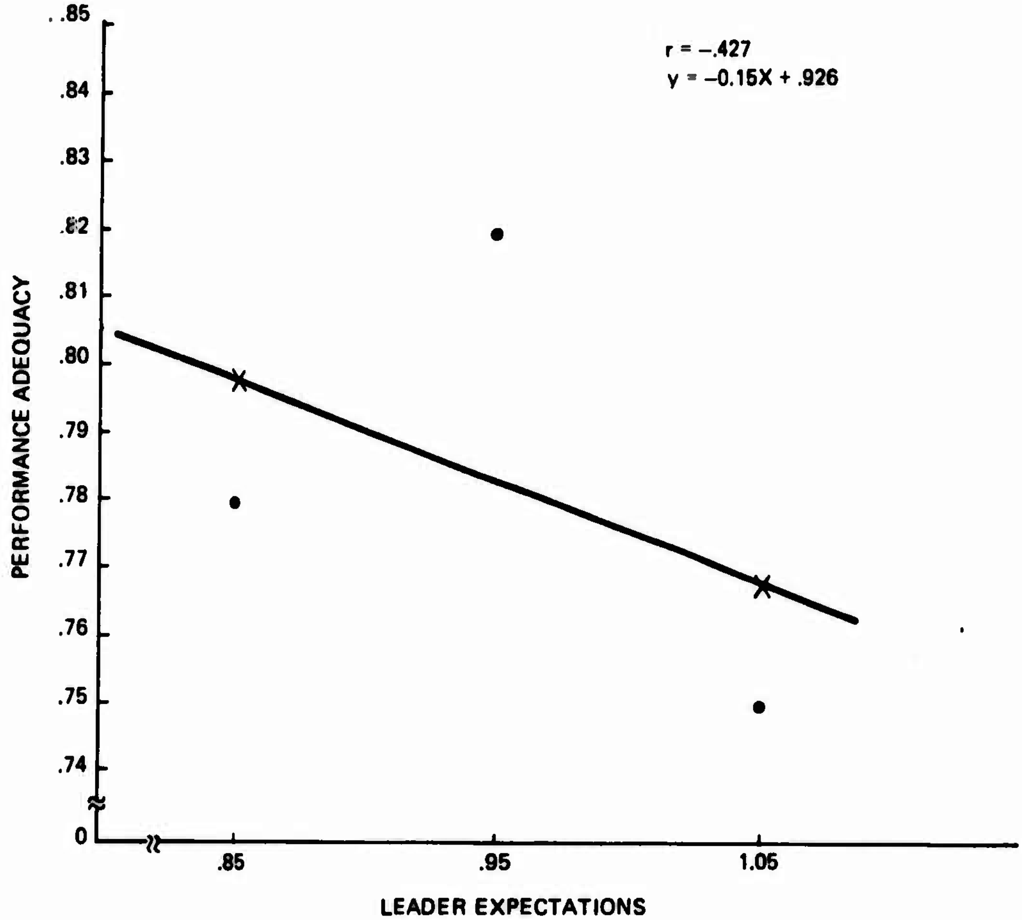

FIGURE 6. PERFORMANCE ADEQUACY AS AFFECTED BY LEADER EXPECTATIONS.

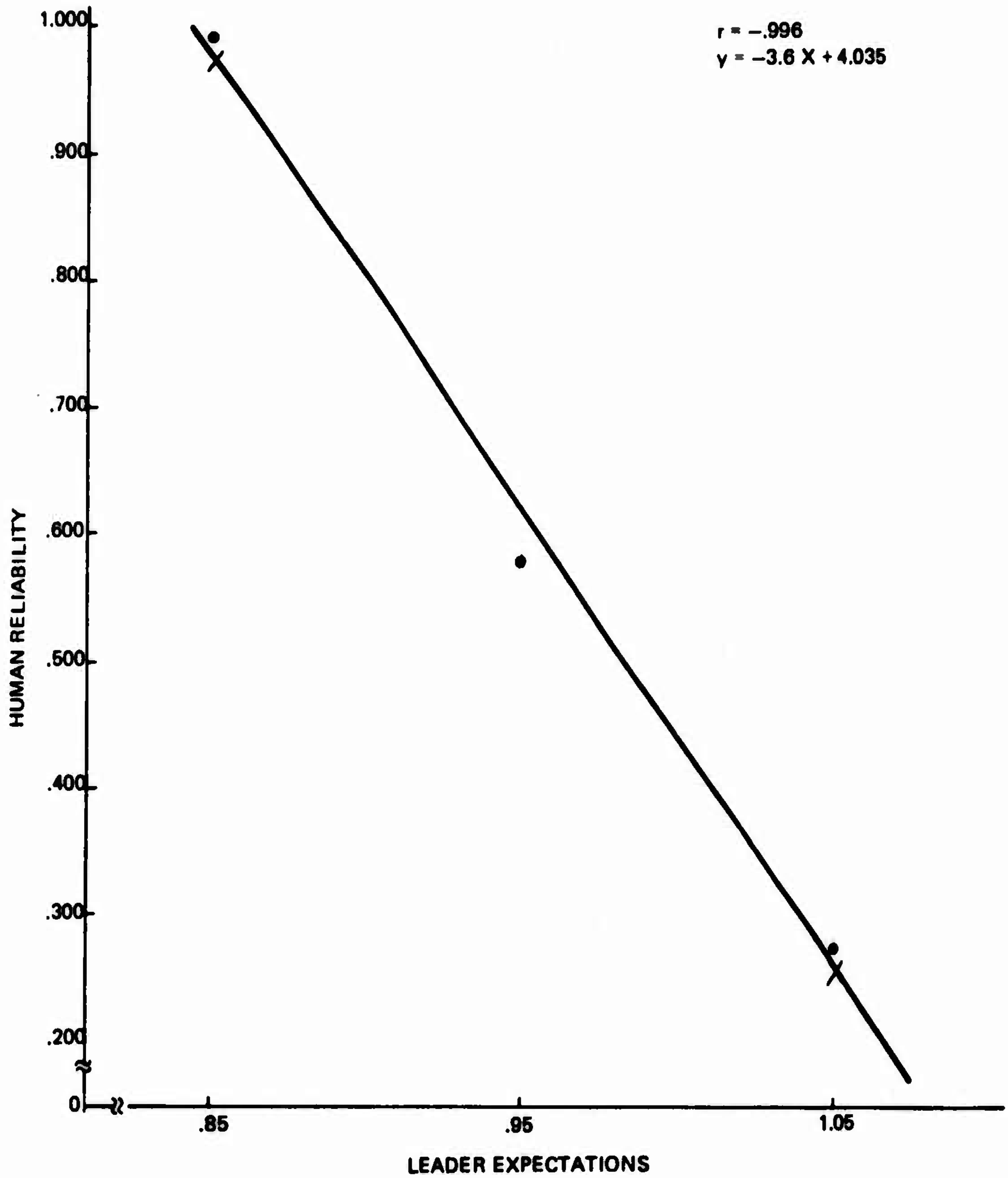

FIGURE 7. HUMAN RELIABILITY AS AFFECTED BY LEADER EXPECTATIONS.

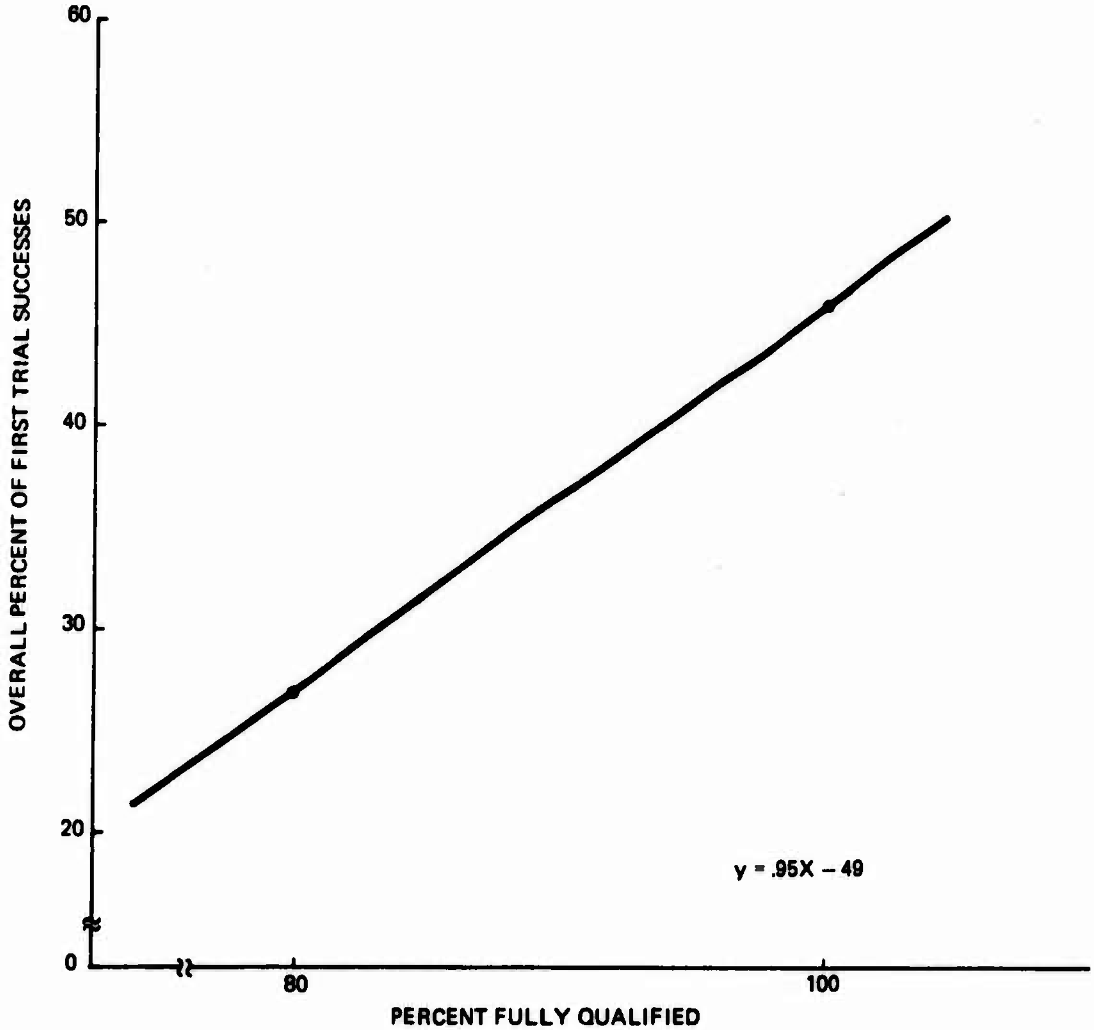

FIGURE 8. OVERALL PERCENT OF FIRST TRIAL SUCCESSES AS A FUNCTION OF PERCENTAGE OF CREW FULLY QUALIFIED.

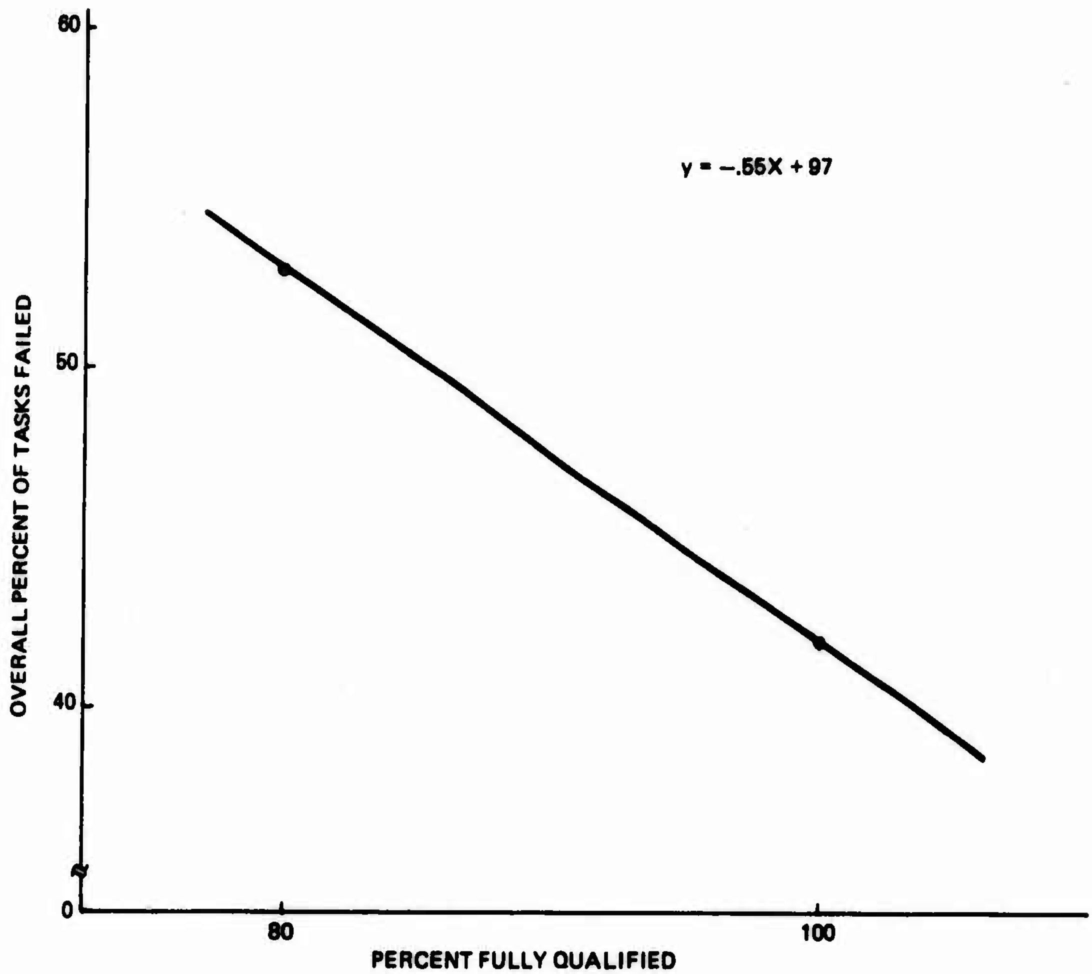

FIGURE 9. OVERALL PERCENT OF TASKS FAILED AS A FUNCTION OF PERCENTAGE OF CREW FULLY QUALIFIED.

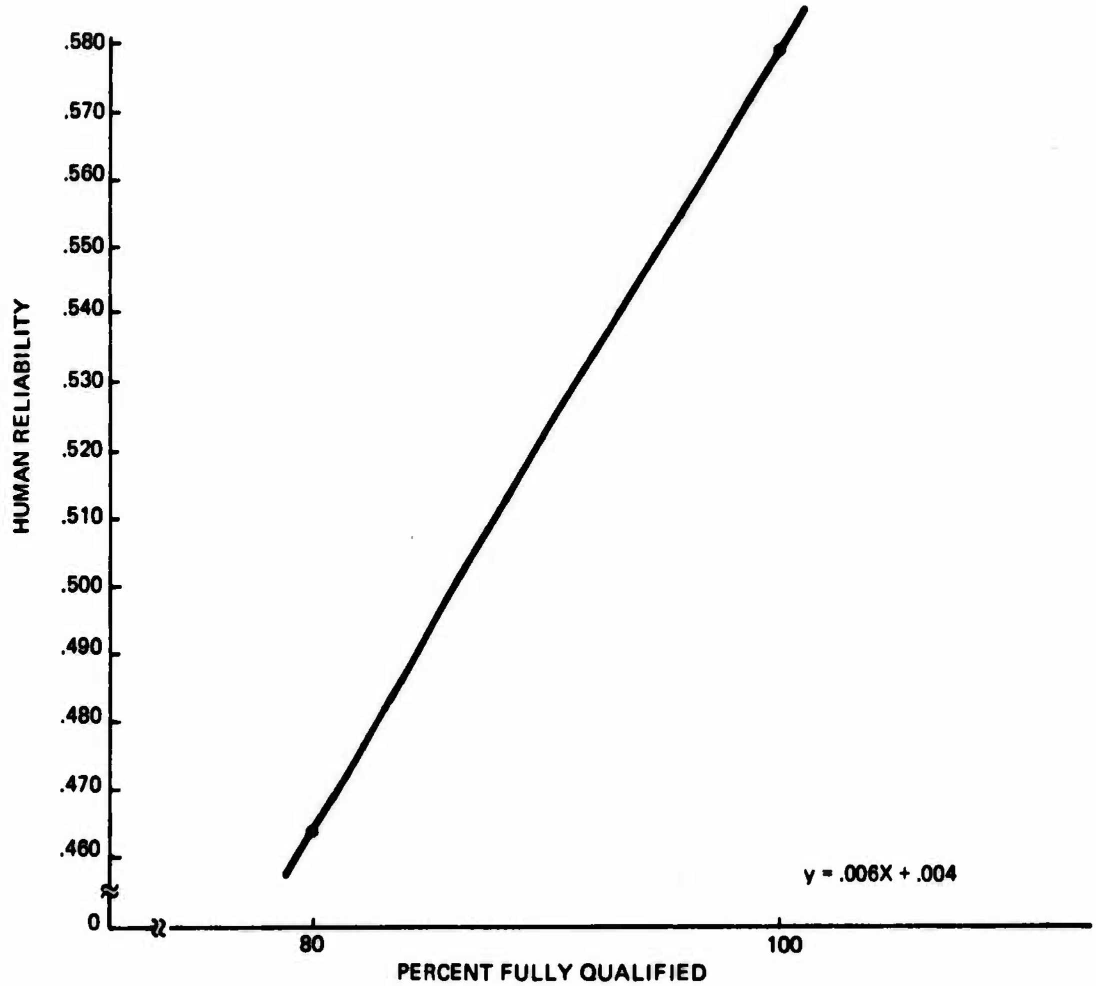

FIGURE 10. HUMAN RELIABILITY AS A FUNCTION OF PERCENTAGE OF CREW FULLY QUALIFIED.

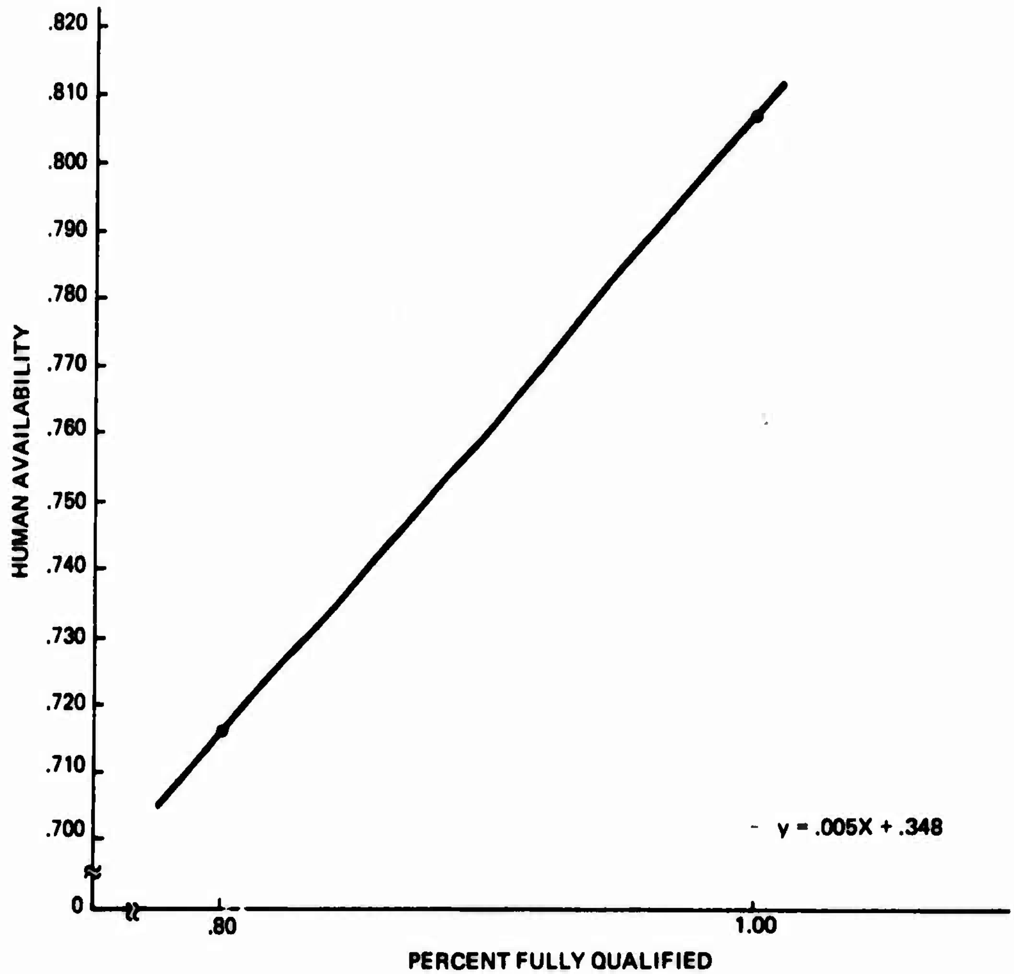

FIGURE 11. HUMAN AVAILABILITY AS AFFECTED BY PERCENT QUALIFIED.

CHAPTER IV

SUMMARY AND DISCUSSION

The purpose of the present work was to provide an estimate of the merit of the combined SQS-26, LAMPS, SQR-19 system from the point of view of the adequacy of the design vis-a-vis human performance. To this end, a previously developed and validated computer simulation model was employed to simulate the performance of the sonar team during a watch which involves processing five targets and eventually attacking one of the targets. The situation was known, at the outset, to impose a heavy workload on the simulation team.

Simulation of the same mission was performed for various operator skill mizes, work speeds, levels of aspiration, and expected levels of performance. The results indicated the predicted human performance to be at a level which would ordinarily be considered unacceptable in an advanced system. The human reliability (baseline condition), on the overall, was predicted to be .58. The baseline overall human availability and mean time to repair values were respectively .81 and .06 hours. These values were also held to possess negative implications relative to the anticipated human performance in the integrated system. Human reliability, as measured here, is essentially an index of the number of mission events failed. Human availability indexes time during which required work is put aside because the team members are performing other work. Human mean time to repair indexes time involved in repeating or touching up previously failed events.

Because the human performance indices were lower than the corresponding equipment oriented indices, the simulation indicated system oriented indices (reliability, availability, maintainability) also tended to be depressed.

Analysis relative to the individual operators, indicated the team supervisor to possess the lowest reliability and availability while the SQS-26 operator was indicated to possess the highest mean time to repair.

Across team members, the baseline number of successes on the first trial was 53 per cent. Increased crew speeds and motivational levels were explored in order to estimate how much this performance might be improved. They were found to be of limited value. An overall 20 per cent speeded up crew increased the percentage of first trial successes only to 57 per cent. A reduction in leader's expectation increased the first trial successes to 83 per cent. However, this value includes a 67 per cent success rate for the critical target reacquisition events.

As is true of any simulation model, a model's output is only as good as the input employed. In the present simulations, the mission scenario input and associated data were prepared in coordination with personnel of the Naval Underwater Systems Center. Accordingly, some confidence may be placed in the inout aspects of the simulation. If the scenario had contained fewer targets to be classified or more time available in which to process targets, a considerably better impression of the system's capability might have been obtained. Further simulations might be indicated for situations involving lighter target configurations.

The discussion within the report emphasized that human performance improvement in the combined system seems to be associated with improving the man/machine interface and the communications network as well as with workload lightening/redistribution and job aid provision. A considerable training requirement was also indicated.

Conclusions

For the conditions and related scenario simulated, the results of the application of the SW4-20 model to the combined SQS-26, LAMPS, SQR-19 system suggested:

1. The human reliability appeared to be depressed and considerably lower than the equipment reliability.

2. Similarly, the human availability and human mean time to repair were depressed below a level which would seem acceptable for an advanced system.

3. Of the four operators considered--supervisor, SQS-26 operator, LAMPS operator, and SQR-19 operator--the supervisor seemed to degrade the overall human reliability and availability most while the SQS-26 operator seemed to degrade the overall human mean time to repair the most.

4. The man/machine interfaces of the system, including the communication links, seem to require design emphasis in order that the operability of the system may be increased.

REFERENCES

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APPENDIX

Scheduled Event Input for Simulations

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED# DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
1	1	0	0	151	1.00	151	0.	151	0.	0	0.	0.25	2
2	4	0	0	3	1.00	3	0.	3	0.	101	0.17	5.00	1
3	4	0	0	4	1.00	4	0.	4	0.	2	0.17	5.00	1
4	4	0	0	51	1.00	51	0.	51	0.	3	0.17	5.00	1
5	4	0	0	6	1.00	6	0.	6	0.	103	0.37	5.00	1
6	4	0	0	7	1.00	7	0.	7	0.	5	0.37	5.00	1
7	4	0	0	52	1.00	52	0.	52	0.	6	0.37	5.00	1
8	8	0	0	178	1.00	178	0.	178	0.	7	0.37	5.00	1
9	9	0	0	157	1.00	157	0.	157	0.	155	0.37	5.00	1
10	4	0	0	158	1.00	158	0.	158	0.	157	0.87	5.00	1
11	4	0	0	159	1.00	159	0.	159	0.	158	0.92	5.00	1
12	4	0	0	13	1.00	13	0.	13	0.	105	0.97	5.00	1
13	4	0	0	14	1.00	14	0.	14	0.	12	0.97	5.00	1
14	4	0	0	53	1.00	53	0.	53	0.	13	0.97	5.00	1
15	4	0	0	162	1.00	162	0.	162	0.	161	1.30	5.00	1
16	4	0	0	17	1.00	17	0.	17	0.	106	1.42	5.00	1
17	4	0	0	18	1.00	18	0.	18	0.	11	1.42	5.00	1
18	4	0	0	54	1.00	54	0.	54	0.	17	1.42	5.00	1
19	4	0	0	20	1.00	20	0.	20	0.	108	1.78	5.00	1
20	4	0	0	[illegible]	1.00	21	0.	21	0.	19	1.78	5.00	1
21	4	0	0	55	1.00	55	0.	55	0.	20	1.78	5.00	1
22	11	0	0	110	1.00	110	0.	110	0.	55	1.78	5.00	2
23	4	0	0	24	1.00	24	0.	24	0.	110	1.78	5.00	1
24	4	0	0	25	1.00	25	0.	25	0.	23	1.78	5.00	1

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
25	4	0	0	166	1.00	166	0.	166	0.	24	1.78	5.00	1
26	4	0	0	56	1.00	56	0.	56	0.	167	1.78	5.00	1
27	4	0	0	28	1.00	28	0.	28	0.	113	2.17	5.00	1
28	4	0	0	29	1.00	29	0.	29	0.	27	2.17	5.00	1
29	4	0	0	57	1.00	57	0.	57	0.	28	2.17	5.00	1
30	14	0	0	31	1.00	31	0.	31	0.	115	2.50	5.00	1
31	14	0	0	32	1.00	32	0.	32	0.	30	2.50	2.67	1
32	14	0	0	58	1.00	58	0.	58	0.	31	2.50	2.67	1
33	4	0	0	34	1.00	34	0.	34	0.	117	2.67	5.00	1
34	4	0	0	35	1.00	35	0.	35	0.	33	2.67	5.00	1
35	4	0	0	59	1.00	59	0.	59	0.	34	2.67	5.00	1
36	11	0	0	119	1.00	119	0.	119	0.	59	2.67	5.00	1
37	4	0	0	38	1.00	38	0.	38	0.	119	2.67	3.50	1
38	4	0	0	39	1.00	39	0.	39	0.	37	2.67	3.50	1
39	4	0	0	60	1.00	60	0.	60	0.	38	2.67	3.50	1
40	4	0	0	41	1.00	41	0.	41	0.	122	3.08	3.50	1
41	4	0	0	42	1.00	42	0.	42	0.	40	3.08	3.50	1
42	4	0	0	61	1.00	61	0.	61	0.	41	3.08	3.50	1
43	11	0	0	124	1.00	124	0.	124	0.	61	3.08	3.50	1
44	4	0	0	45	1.00	45	0.	45	0.	124	3.08	3.50	1
45	4	0	0	46	1.00	46	0.	46	0.	44	3.08	3.50	1
46	4	0	0	62	1.00	62	0.	62	0.	45	3.08	3.50	1
47	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
48	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED# DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
49	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
50	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
51	5	0	0	102	1.00	102	0.	102	0.	3	0.17	5.00	2
52	5	0	0	104	1.00	104	0.	104	0.	6	0.37	5.00	1
53	5	0	0	160	1.00	160	0.	160	0.	13	0.97	5.00	1
54	5	0	0	107	1.00	107	0.	107	0.	17	1.42	5.00	1
55	5	0	0	109	1.00	109	0.	109	0.	20	1.78	5.00	1
56	5	0	0	167	1.00	167	0.	167	0.	24	1.78	5.00	1
57	5	0	0	114	1.00	114	0.	114	0.	28	2.17	5.00	1
58	15	0	0	116	1.00	116	0.	116	0.	31	2.50	2.67	1
59	5	0	0	118	1.00	118	0.	118	0.	34	2.67	3.50	1
60	5	0	0	120	1.00	120	0.	120	0.	38	2.67	3.50	1
61	5	0	0	123	1.00	123	0.	123	0.	41	3.08	3.50	1
62	5	0	0	125	1.00	125	0.	125	0.	45	3.08	3.50	1
63	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
64	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
65	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
66	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
67	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
68	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
69	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
70	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
71	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
72	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
73	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
74	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
75	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
76	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
77	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
78	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
79	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
80	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
81	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
82	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
83	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
84	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
85	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
86	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
87	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
88	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
89	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
90	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
91	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
92	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
93	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
94	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
95	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
96	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED# DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT 1	PROBABILITY 1	NEXT EVENT 2	PROBABILITY 2	NEXT EVENT 3	PROBABILITY 3	PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
97	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
98	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
99	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
100	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
101	3	0	0	2	1.00	2	0.	2	0.	151	0.17	5.00	1
102	6	0	0	152	1.00	152	0.	152	0.	3	0.17	5.00	2
103	3	0	0	5	1.00	5	0.	5	0.	153	0.37	5.00	1
104	6	0	0	154	1.00	154	0.	154	0.	5	0.37	5.00	2
105	3	0	0	12	1.00	12	0.	12	0.	159	0.97	5.00	1
106	3	0	0	16	1.00	16	0.	16	0.	162	1.42	5.00	1
107	6	0	0	163	1.00	163	0.	163	0.	17	1.42	5.00	2
108	3	0	0	19	1.00	19	0.	19	0.	164	1.78	5.00	1
109	6	0	0	165	1.00	165	0.	165	0.	20	1.78	5.00	2
110	3	0	0	23	1.00	23	0.	23	0.	22	1.78	5.00	1
111	6	0	0	112	1.00	112	0.	112	0.	24	1.78	5.00	2
112	12	0	0	113	1.00	113	0.	113	0.	111	1.78	5.00	1
113	3	0	0	27	1.00	27	0.	27	0.	112	2.17	5.00	1
114	6	0	0	168	1.00	168	0.	168	0.	28	2.17	5.00	2
115	3	0	0	30	1.00	30	0.	30	0.	169	2.50	2.67	1
116	16	0	0	170	1.00	170	0.	170	0.	31	2.50	2.67	2
117	3	0	0	33	1.00	33	0.	33	0.	171	2.67	3.50	1
118	6	0	0	172	1.00	172	0.	172	0.	34	2.67	3.50	2
119	3	0	0	37	1.00	37	0.	37	0.	36	2.67	3.50	1
120	6	0	0	121	1.00	121	0.	121	0.	38	2.67	3.50	2

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED# DAY 1 TEST

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
121	12	0	0	173	1.00	173	0.	173	0.	120	2.67	3.50	1
122	3	0	0	40	1.00	40	0.	40	0.	175	3.08	3.50	2
123	6	0	0	176	1.00	176	0.	176	0.	41	3.08	3.50	1
124	3	0	0	44	1.00	44	0.	44	0.	43	3.08	3.50	1
125	6	0	0	126	1.00	126	0.	126	0.	45	3.08	3.50	2
126	12	0	0	177	1.00	177	0.	177	0.	125	3.08	3.50	1
127	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
128	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
129	4	0	0	178	1.00	178	0.	178	0.	3	0.10	5.10	3
130	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
131	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
132	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
133	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
134	4	0	0	178	1.00	179	0.	178	0.	0	0.10	5.10	3
135	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
136	4	0	0	178	1.00	178	0.	175	0.	0	0.10	5.10	3
137	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
138	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
139	4	0	0	178	1.00	178	0.	178	0.	3	0.10	5.10	3
140	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
141	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
142	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
143	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
144	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED# DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
145	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
146	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
147	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
148	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
149	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
150	4	0	0	178	1.00	178	0.	178	0.	0	0.10	5.10	3
151	2	0	0	101	1.00	101	0.	101	0.	0	0.17	5.00	2
152	7	0	0	153	1.00	153	0.	153	0.	3	0.17	5.00	1
153	2	0	0	103	1.00	103	0.	103	0.	152	0.37	5.00	2
154	7	0	0	155	1.00	155	0.	155	0.	6	0.37	5.00	1
155	8	0	0	156	1.00	156	0.	156	0.	154	0.37	5.00	2
156	10	0	0	9	1.00	9	1.00	9	1.00	155	0.37	5.00	2
157	7	0	0	10	1.00	10	0.	10	0.	156	0.87	5.00	1
158	7	0	0	11	1.00	11	0.	11	0.	157	0.92	5.00	1
159	2	0	0	105	1.00	105	0.	105	0.	158	0.97	5.00	2
160	7	0	0	161	1.00	161	0.	161	0.	13	0.97	5.00	1
161	7	0	0	15	1.00	15	0.	15	0.	160	1.30	5.00	1
162	2	0	0	106	1.00	106	0.	106	0.	161	1.42	5.00	2
163	7	0	0	164	1.00	164	0.	164	0.	17	1.42	5.00	1
164	2	0	0	108	1.00	108	0.	108	0.	163	1.78	5.00	2
165	7	0	0	22	1.00	22	0.	22	0.	20	1.78	5.00	1
166	2	0	0	26	1.00	26	0.	26	0.	165	2.17	5.00	2
167	7	0	0	111	1.00	111	0.	111	0.	166	1.78	5.00	1
168	7	0	0	169	1.00	169	0.	169	0.	28	2.17	5.00	1

SCHEDULED EVENT SEQUENCE DATA

FOR 178 SCHEDULED EVENTS OF DAY 1 ENTITLED DAY 1 TEST

RTU CODE
1-REPEAT
2-TOUCHUP
3-NEXT EVENT

EVENT NO.	TYPE	THRESHOLD SET UNITS/HR	UNITS	NEXT EVENT AND PROBABILITY 1		2		3		PRECEDENT EVENT NO.	START TIME	TIME LIMIT	REPEAT/TOUCHUP CODE
169	2	0	0	115	1.00	115	0.	115	0.	168	2.50	2.67	2
170	17	0	0	171	1.00	171	0.	171	0.	31	2.50	2.67	1
171	2	0	0	117	1.00	117	0.	117	0.	170	2.67	3.50	2
172	7	0	0	36	1.00	36	0.	36	0.	34	2.67	5.00	1
173	7	0	0	174	1.00	174	0.	174	0.	38	2.67	3.50	1
174	10	0	0	175	1.00	175	0.	175	0.	173	2.67	3.50	2
175	2	0	0	122	1.00	122	0.	122	0.	174	3.08	3.50	2
176	7	0	0	43	1.00	43	0.	43	0.	41	3.08	3.50	1
177	7	0	0	178	1.00	178	0.	178	0.	45	3.08	3.50	1
178	10	0	0	0	1.00	0	0.	0	0.	177	3.08	3.50	2

APPENDIX C

Human Reliability Demonstration Guidelines

HUMAN PERFORMANCE RELIABILITY DEMONSTRATION GUIDELINES

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prepared for

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by

Applied Psychological Services, Inc.
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under

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FOREWORD

Human reliability is a necessary consideration when the contribution of system operators to the unreliability of a total system is an issue of interest. Human reliability deals with that aspect of total system unreliability attributable to human error or human induced failure. The human reliability concept includes all aspects of system operation and is measured in terms of demonstrated operator/maintainer performance.

These Human Performance Reliability Demonstration Guidelines present desirable steps and procedures for employment when the need exists for assuring that an equipment unit, subsystem, or system are not limited by human failure. The Guidelines are not "standards" or "specifications" and in no way, are the Guidelines intended to replace, supercede, or minimize such documents as MIL-STD-471 (Maintainability Demonstration), MIL-STD- 721B (Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety), MIL-STD-756A (Reliability Prediction), and the like. While the Guidelines could lead to a formal "standard" or "specification," practical military service and industrial experience with their use, implementation, advantages, and associated problems seems required before such finalization can take place.

In a sense, the Guidelines represent a first step towards quality control and assurance from the point-of-view of the interface of the human and the equipment units in an equipment unit/subsystem/system. Recent experience has indicated this interface to constitute one of the weakest, if not the weakest, design links. Quite often, such softness in a design is compensated for by increased training requirements, heightened manning, or by using higher rated operators/maintainers. However, such fixes are costly and not always possible. For example, recent information indicated manpower costs to represent 55 per cent of the total life-cycle cost of a modern ship.

The development of the Guidelines was iterative in nature and considerable reliance was placed on the advice and opinions of knowledgeable persons holding Governmental equipment development responsibility and on the insights of industrial design and development personnel. At the outset, a complete outline of the Guidelines was prepared. A group of industrial and Governmental representatives was called together to critique the outline with specific reference to the following questions:

- Can you live with such a set of standards?
- What part(s) can't you live with?
- What should be changed and how?
- What are the cost impacts?

- How will your management react to various aspects of the standards?

- What is included which should be deleted?

- What included material should be emphasized more? Deemphasized?

- How should the order of the parts be modified?

- What included content material is useless? Wrong?

- What material is impractical and how could it be made more practical?

- What terminology is unclear or not consistent with ordinary use?

- What content may conflict with policies of your organization?

The comments of these persons were considered, and appropriate adjustments were made in the preliminary outline. Then, a first draft was prepared and distributed to a set of reviewers who, again, represented the civil and the Governmental sectors. The comments and opinions of the reviewers were integrated into this final form of the Guidelines. Quite obviously, the responsibility for the final product is that of Applied Psychological Services alone.

In developing the Guidelines, there was a deliberate attempt to employ terminology relative to the human in a system which parallels that applied to equipment units, e.g., human reliability, human mean time to repair, human availability. Moreover, there was an attempt to define such terms, relative to the human in the system, in a manner which parallels the use of these terms as they are applied to the equipment. This emphasizes our thinking that total reliability, availability, and maintainability are functions of both human and equipment considerations.

The human reliability demonstration is not intended to establish the human reliability. Reliability never is a static or constant figure. It is determined at various points in the life cycle of a system and may vary over these points as a function of a wide variety of influences. Similarly, these Guidelines cannot be considered static. As experience with the Guidelines develop, areas for revision and update will certainly develop.

Finally, we note that human reliability is a product of proper design--not a consequence of a test or demonstration.

APPLIED PSYCHOLOGICAL SERVICES, INC.
May 1977

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1. Introduction

1.1 Purpose. These Guidelines consider the test methods and procedures which can be applied in order that the attainment of a predicted or desired level of human reliability can be demonstrated.

1.2 Scope. This set of human performance reliability demonstration guidelines is designed to be compatible with any formal human engineering and equipment reliability program which is implemented throughout the development of an equipment/subsystem/system. The Guidelines are applicable to mechanical, electromechanical, electronic, and electrical equipment, subsystems, and systems.

The human performance reliability (HR) demonstration may overlap in part with the maintainability demonstration (MIL-STD-471). These two demonstrations may, at times, consider the same set of tasks from different points of view (i.e., with different criteria). Similarly, the human performance reliability demonstration may be integrated with the maintainability demonstration.

1.3 Application. Human reliability is an important consideration whenever attainment of a desired level of integrated system reliability is to be demonstrated. As such, human reliability is a part of a total program and not a substitute for a human factors, reliability, or quality assurance program.

1.4 Relationship to Equipment and Integrated System Reliability. The various aspects of human reliability are viewed in a fashion which parallels the treatment of equipment reliability and integrated system reliability. With respect to each, the following measures provide unique information: reliability, availability, mean time to repair (MTTR), and mean time between failures (MTBF). The interpretation of these terms with respect to human performance is:

a. Human reliability is the probability that the humans in a system will be able to complete required performance without error and within time constraints.

b. Human availability is the proportion of assigned time that human operators and/or maintainers are available to conduct required tasks.

c. Human MTTR is a measure of the mean time required for an operator to correct and accurately execute a previously failed subtask.

2. Terms and Definitions:

ASVAB (Armed Services Vocational Aptitude Battery): A paper and pencil test, designed and developed by the armed forces, for assessing aptitude for a wide variety of civil and military jobs.

Criticality: The extent to which failure to perform properly a given subtask, subtask sequence, or task will degrade attainment of mission objectives or will degrade system performance.

Empirical: Related to facts or data as opposed to theory and speculation.

Fix-up: Effort expended in redoing a part of a task which was not successfully completed.

Frequency: A measure of how often a given operational or maintenance task or subtask occurs during actual equipment, subsystem, or system employment.

Frequency-Criticality Matrix: An integrated representation of the frequency of occurrence and of the criticality of each task performed by operators.

Hard Copy: A product of job or test performance which may be repeatedly and independently scored and measured.

HR Demonstration: Mock operational test of the ability of anticipated operational personnel, or their equivalents, to function without failure in their anticipated role. This demonstration may be preceded by any number of developmental HR tests at any stage in the development of the equipment/subsystem/system.

Norm: A single value or a range of values constituting the usual performance of a given group.

Operators: The technicians operating an equipment/subsystem/system during the HR demonstration.

Percentile Equivalent: A score representing the proportion of persons in a given sample who fall below a given raw score.

Reliability of Measurement: The consistency or repeatability of a performance measure. One particularly relevant form of reliability is termed interrater reliability which refers to the agreement between various judges of the same performance.

Subtask: A logical unit of performance which is not logically reduceable to a smaller, observable unit.

Task: A logical group of actions which form a coherent set of activities. Tasks are more global in scope than subtasks as customarily included in a task analysis. For example, an equipment alignment and calibration process which requires 40 minutes and involves many interactive steps may be defined as one task.

Examples of tasks are:

> making a parts replacement
>
> operating an equipment under a specific set of circumstances
>
> performing corrective maintenance

performing preventive maintenance

making a periodic check

Technical Training: The totality of planned circumstances, instructions, and directed activity contributing to performance or learning.

Theoretical: A general principle, supported by considerable data, proposed as an explanation.

Transient Copy: A product of job or test performance which is momentary in nature, e.g., a measurement which must be made during a circumscribed period of time. This term also applies to a product which is destroyed by the measurement process.

Vocational Training: Any form of training, whether given in school or elsewhere, whose purpose is to fit an individual for effective pursuit of a recognized, profitable employment.

3. Detailed Requirements: --Preparation for Conduct of Demonstration. All actions should be completed prior to conducting the actual HR demonstration.

3.1 Demonstration Plan. Prior to the completion of any subsequent steps, the contractor should submit a "HR demonstration plan. This plan should include, but not be limited to: (a) a detailed explanation of how he will complete the various procedures and actions indicated throughout these Guidelines, (b) a milestone chart with anticipated date of milestone completion, (c) names of responsible personnel and contacts, and (d) management information.

3.2 Task/Subtask Identification

3.2.1 Identification of Tasks. A list of tasks should be developed which, as a whole, exhaustively describes the performance of the human operator(s) in the system.

3.2.2 Responsibility. Responsibility for the identification of tasks should rest with the contractor.

3.2.3 Approval. Approval of the procuring agency should be sought for this partitioning of duties into a task list prior to further use of the task list in the development of the HR demonstration.

3.2.4 Task Frequency. The relative frequency of execution of each task should be determined. This determination should consider normal operation, emergency operation, and operation under degraded conditions.

3.2.5 Method. The frequency of occurrence of each task may be determined using either empirical or theoretical methods. Usually, the same method will be used for all tasks in the task list.

For example, the frequency of occurrence of each task may be determined by tallying the number of occurrences of that task during a simulated or actual application of the system. This application would include the equivalent of at least one full day's operation with both normal, emergency, and degraded conditions considered.

Or, the frequency of occurrence of each task may be determined from an analysis of the mission profile of each type of application of the system together with a determination of the relative frequency of occurrence of each type of application. Each task would be assigned to the highest frequency level indicated by this analysis. For example, if a task is respectively judged to occur with low, low, and high frequency for the normal, emergency, and degraded modes, the task would be assigned a high frequency.

3.2.6 Levels. Criteria for three levels of frequency should be developed. These levels should be termed "low," "moderate," and "high" frequency.

3.2.7 Task Criticality. The criticality of the execution of each task should be determined by developing estimates of the effects of improper performance of the task on the attainment of mission objectives or on system performance. To this end, each task may be judged on a hierarchical scale composed of three categories--"low" criticality, "moderate" criticality, and "high" criticality.

3.3 Sample Selection. Because the total number of tasks included in the task list will be more than the number of tasks to be included in the HR demonstration, a sample of the tasks will be required. The goal of this sampling is to assure that the tasks selected for inclusion in the demonstration are truly representative of the population of tasks included in the task list. Any acceptable sampling scheme may be employed. One scheme is to first decide on the total number of tasks which can be accomplished in the HR demonstration. It is anticipated that about one week will ordinarily be allocated to the HR demonstration. The decision relative to the total number of tasks to be included in the demonstration can be made in view of the time available and the mean amount of time required to organize and implement the demonstration of each task.

Once the total number of tasks to be included in the demonstration is known, a two stage proportional sample is drawn in such a manner that twice the number of tasks to be included in the final demonstration is selected. Details of one method for this selection are shown below.

The first step involves construction of a frequency-criticality distribution which will serve as the basis for the selection of tasks nominated for inclusion in the HR demonstration. This distribution integrates the frequency and criticality data for each task. Each task is categorized into one cell of a 3 x 3 frequency-criticality matrix. Figure 1 shows how this matrix should appear. Each cell entry in Figure 1 contains the task number of each task, identified and assigned to a frequency and to a criticality category previously. For example, task 26 is low on both criticality and frequency; task 23 is a high frequency-high criticality task.

The second step involves determining the number of tasks at each criticality (row total) and the number of tasks at each frequency level (column total). The row totals will sum to the total number of tasks (50 in this case) as will the column totals.

	FREQUENCY			
	Low	Moderate	High	Raw Total
Criticality Low	1,3,26,27, 44,45,46	16,17,18,32, 48,49	4,24,25,40, 41,42	19
Moderate	15,20,28, 29	2,19,20,43, 50	5,6,31,33	13
High	8,9,10,21, 34,35	11,12,13, 22,36,37,38	7,14,23, 39,47	18
Column Total	17	18	15	50

Figure 1. Example of frequency-criticality matrix.

The relative proportion of tasks to be selected from each cell is calculated as the product of the appropriate frequency and criticality divided by the sum of the cross products (appropriate row total multiplied by column total). The sum of the cross products should be calculated to verify accuracy. However, it will always be equal to the square of the total number of tasks. In the example, for low frequency and moderate criticality there is a cross product of 221 (13 x 17) and the cross product sum is 2500 (50^2). The resulting proportion is .0884 (221/2500) which when rounded as a percentage is equal to 9. That is, 9 per cent of however many tasks are to be selected are taken from the low frequency-moderate criticality cell of the matrix. If a total of 20 tasks (i.e., 10 tasks are to be included in the demonstration; accordingly, a total of 20 is to be selected at this stage) is required then two tasks (20 x .0884= 1.768 rounded to 2) would be randomly selected from this cell. In the case in which more tasks are designated to be drawn from a cell than the cell contains (poor planning in the original assignment of tasks to levels), then the tasks should be randomly selected on the basis of relative proportions, from other cells. The sampling should be done without replacement.

3.4 Scoring. For each task selected as the result of the procedures of 3.3, a recording or scoring sheet is developed. The purpose of the scoring sheet is to allow scoring performance on the individual subtasks of the task. There are several possible types of scoring sheets. One of the most popular methods is a sequential (checklist) scoring sheet. Another possible method is through a technician recorded sheet.

3.4.1 Sequential Scoring Sheet. To construct a sequential human performance scoring sheet for a task, the task is decomposed into the sequential subtasks which must be correctly performed if the task is to be completed. Each of the subtasks is then sequentially listed for scoring by an examiner while he observes the performance of a technician on the task. Time allowances, if appropriate, are also listed on the recording sheet. An example of such a recording sheet for a hypothetical detection and tracking task is presented as Figure 2.

3.4.2 Technician Recorded Scoring Sheet. The technician recorded scoring sheet is useful when several technicians can be tested at once. The kinds of information which can be recorded by a technician include measurements, locations, or interpretations. The technician recorded scoring sheet should not test reading or writing skills--only actual performance. The written response made by the technician should be limited to such pencil entries as a checkmark, underlining, or a simple entry. Examples of technician recorded scoring sheets for two hypothetical tasks, an instrument reading and a target classification task, are presented in Figures 3 and 4.

3.4.3 Criteria for Failure. For each subtask (or item in a technician recorded scoring sheet) the contractor should develop fully objective criteria against which technician performance may be assessed.

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3.4.3 Criteria for Failure. For each subtask (or item in a technician recorded scoring sheet) the contractor shall develop fully objective criteria for against which technician performance may be assessed.

HUMAN RELIABILITY EVALUATION AN/____ SONAR

Observer:______________________________ **Technician Identification**________________________ **Date:**____________

Task: Detection and track of an xx db target at range of x kiloyards under sea state x, target speed x, and own ship speed x.

Subtask	First Attempt Time	First Attempt Time Re-quired	First Attempt Score	Fix-Up Time	Fix-Up Time Re-quired	Fix-Up Score
1. Report target presence	____	____	S F	____	____	S F
2. Adjust fine bearing	____	____	S F	____	____	S F
3. Reports target azimuth within ±x°	____	____	S F	____	____	S F
4. Reports target range within ±x°	____	____	S F	____	____	S F
5. Sets range scale to xx yards	____	____	S F	____	____	S F
6. Slews cursor to target	____	____	S F	____	____	S F
7. Prints cursor	____	____	S F	____	____	S F
8. Sets pulse length to ______	____	____	S F	____	____	S F
9. Sets transducer selection to _____	____	____	S F	____	____	S F
10. Sets filter selection to _____	____	____	S F	____	____	S F
. . . (etc)	(etc.)	(etc.)	(etc.)	(etc.)	(etc.)	(etc.)
			TOTAL S_____			TOTAL S____
			TOTAL F_____			TOTAL F____

I certify that this scoring reflects my true observations during this demonstration and that the scoring was independently derived.

____
Evaluator's Signature

Comments:

Safety precaution violations:

Figure 2. Example of sequential scoring sheet.

INSTRUMENT READING

Technician Identification ______________________ Date ______________

In column I place the numerical reading found on the instrument.
In column II indicate with a "yes" or "no" whether or not the reading is within the normal operation range.
In columns III and IV give the maximum and minimum readings at which it would still be safe to operate the engine.

Time Limit: Ten minutes.

Instrument Number	I Reading	II Within Norm Range (yes or no)	III Maximum Safe	IV Minimum Safe	I		II		III		IV	
1.					S	F	S	F	S	F	S	F
2.					S	F	S	F	S	F	S	F
3.					S	F	S	F	S	F	S	F
4.					S	F	S	F	S	F	S	F
5.					S	F	S	F	S	F	S	F
6.					S	F	S	F	S	F	S	F

This section is for scoring only. Make no marks on this section.

TOTALS S ______

TOTALS F ______

Figure 3. Example of technician recorded scoring sheet.

TARGET CLASSIFICATION

Technician Identification:______________________________ Date________________

Directions: The system is fully energized, checked, and working normally. Targets will appear, one at a time, over the next 30 minutes. As each target appears, enter the time you detected it and its range, azimuth, and evaluation. Also, attempt to classify it. Enter your answers in the spaces below. The main thing is to treat each target as it appears. Work carefully but don't waste time.

Target	Time of Detection	Range	Azimuth	Evaluation	Classification
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________
______	________	______	______	__________	____________

Figure 4. Additional example of technician recorded scoring sheet.

Examples of Objective Criteria

a. Completes circuit check within x minutes

b. Torques to ±x pounds

c. Detects target within x minutes

Examples of Nonobjective Criteria

a. Expeditiously completes circuit check

b. Adjusts torque appropriately

c. Speedily detects target

3.4.4 Interrater Reliability. Task scoring which depends on observation of the technician as he performs the task or on judgments should produce scores which are in demonstrable agreement when the observations are performed by different observers. Such between rater (scorer) data can be collected during the HR demonstration and may be based on a 20 per cent sample of the tasks included in the demonstration. However, failure to demonstrate an interater reliability of .85 or greater shall contitute failure of the total demonstration. The interrater reliability may be quantified by correlation, analysis of variance, or other standard techniques. An interater reliability less than .85 will require demonstration repetition and such action as: further training of evaluators, redefinition of success and failure points within the tasks, selection of different tasks, and development of improved scoring sheets.

An example of the analysis of variance technique for the estimation of between rater agreement follows:

Example:

Assume that three evaluators have observed the performance of technicians performing four tasks. The score given on each task by each evaluator is shown in columns 1, 2, and 3 below.

Task (N)	Evaluator (K) 1	2	3	TOTAL
1	.88	.85	.87	2.60
2	.76	.78	.77	2.31
3	.94	.95	.93	2.82
4	.91	.90	.92	2.73
TOTAL	3.49	3.48	3.49	G= 10.46
Σx^2	3.06	3.04	3.06	

$$(1) = \frac{G^2}{KN} = \frac{109.4116}{3 \times 4} = 9.11763$$

$$(2) = \Sigma(\Sigma\chi^2) = 9.1682$$

$$(3) = \frac{\Sigma T^2{}_j}{N} = \frac{3.49^2 + 3.48^2 + 3.49^2}{4} = 9.11765$$

$$(4) \quad \frac{\Sigma P^2{}_i}{K} = \frac{2.60^2 + 2.31^2 + 2.82^2 + 2.73^2}{3} = 9.16713$$

SS between tasks= (4) - (1) = .04950
SS within tasks = (2) - (4) = .00107
SS between judges= (3) - (1) = .00002
SS residual= (2) - (3) - (4) + (1)= .00105
SS total= (2) - (1) = .05057

Summary of Analysis

Source of Variance	SS	df	MS
Between tasks	.04950	3	.01650
Within tasks	.00107	8	.00013
between judges	.00002	2	-
residual	.00105	6	-
TOTAL	.05057	11	

$$\text{Agreement between raters} = 1 - \frac{\text{MS within tasks}}{\text{MS between tasks}} = 1 - \frac{(.00013)}{.01650} = .992$$

3.4.5 Unobtrusive Measures. When the scoring depends on direct rater observations, effort should be made to assure that the observations will influence the ongoing behavior minimally.

4. Detailed Requirements: Conduct of the HR demonstration.

4.1 Task Selection and Order of Administration. A sample of the tasks identified by the methods of paragraph 3.3 should be chosen for inclusion in the HR demonstration. This sample should be a 50 per cent random sample of the tasks selected by methods of paragraph 3.3. The eligible tasks should be placed in a hat. Then, the first task to be demonstrated should be selected and implemented. After the demonstration of the first task has been completed, the second task should be drawn and implemented. This procedure continues until the sampling requirements have been met; i.e. one half of the tasks have been selected and demonstrated.

In some cases the Government may specify a special sample of tasks (e.g., all tasks of a given level of criticality) for inclusion in the final HR demonstration. In these cases, the sample of tasks should include all such tasks and a representative (random) sample of the remaining tasks.

4.2 Test Methods.

4.2.1 Task Presentation. The tasks selected for inclusion in the HR demonstration should be presented in the random order in which they are drawn. The tasks which the technicians will be asked to perform during the HR demonstration should be presented in a context that duplicates to the extent possible that which will be found during likely applications of the equipment/subsystem/system.

4.2.2 Non-Random Sequences. In the unlikely event that equipment set up requirements may dictate schedule rearrangement, the random sequence of tasks may be rearranged.

4.2.3 Inter-Task Presentation Time. Whenever possible, the tasks should be presented by the state of the equipment/subsystem/system and not verbally by an administrator. The time between task presentations will be a function of the time required for equipment set up. Long breaks between tasks should be avoided and may constitute a basis for a non-random task presentation sequence.

4.2.4 Equipment Failure during Demonstration. In the event of an equipment failure during a task demonstration, the demonstration should be interrupted and after restoration of the equipment to operational status, a substitute task should be drawn from the bank of tasks. The substitute task will serve as a replacement for the original task.

4.2.5 Operator Teams. In the event that more than one operator or one maintainer team is employed for the HR demonstration, the interaction among the individuals and the teams should be controlled. The various teams should function independently. No one individual should be a member of more than one team.

4.2.5.1 Intrateam Relationships. The members of each team should function with a level of autonomy similar to that expected during actual operation of the equipment/subsystem/system. Each team member should assume a level of responsibility as might be expected in actual applications.

4.2.6 Task Presentation Directions. Task instructions should be presented in a standard form and should be read aloud by an examiner to the participating technician(s) while the technician(s) read(s) the directions silently. These directions should contain all information required by the technician for completing the task and no additional information. An example of such directions is presented in Figure 5.

4.2.7 Information Provided to Technicians. Once started on a task, the technician performing the task should receive no help or guidance from the evaluators, test administrators or other personnel present. Administrators will provide only that information which is included in the task presentation directions. Where inadequate performance (subtask failure) is not noted by the technician, it should be pointed out to him only if subsequent subtask performance will be affected.

TASK PRESENTATION DIRECTIONS
TARGET DETECTION AND TRACK

Purpose: The purpose of this aspect of the HR demonstration is to demonstrate the ability of operators to detect and track targets on the AN/_____ system.

Your Task: When I say "start," seat yourself at the equipment and monitor the system in a "normal" manner. Report, as early as you are sufficiently confident, the range and azimuth of any target you detect and prosecute each target including full lock on and track over the course of the demonstration. Be sure to follow all required procedures for assuring early detection and full track. If you lose a target, go through the normal reacquisition procedures. If you have any questions ask them now. No questions will be answered during the demonstration.

Equipment: The AN/_____ has been turned on and is operational. However, you may make any adjustments you desire.

Scoring: You will be scored on how quickly you report each target, how accurately you report it, and how well you prosecute it. You will be downgraded if you fail to follow correct procedures or if you violate equipment or human safety precautions.

Do you have any questions? Start.

Figure 5. Example of task presentation directions.

4.3 Conditions of Test. The testing conditions should realistically duplicate the various conditions under which the system operates. The resources made available for use should be those supplies and equipment which are expected to be commonly available when the system is in actual use.

4.3.1 Specification of Resources. The resources that will be made available during the final HR demonstration should be listed prior to the onset of the demonstration. Procuring agency approval of the list should be obtained.

4.3.1.1 Apparatus. Testing will be done on the actual equipment/subsystem/system under consideration. This equipment should be identical in all major respects to the actual equipment planned for delivery. Major respects are those aspects which might affect human performance.

4.3.1.2 Test Equipment, Tools, and Supplies. Only standard test equipment, tools, and supplies which are expected to be available during the normal operation of the equipment/subsystem/system should be permitted for use during the HR demonstration.

4.3.2 Time and Duration of Test. The time of day of testing and the duration of testing on any one day need not be consonant with the time of day and length of operator/team shift anticipated for the equipment/ subsystem/system in actual application. However, no one operator/team should be tested for a length of time greater than that anticipated for actual application. Similarly, turnover of personnel within the length of time of a typical work/shift should be avoided.

4.3.3 Technician and Evaluator Selection and Training. The validity of the HR demonstration is dependent on the qualifications and the degree of training of both the technicians and the evaluators. All aspects of such selection and training should be carefully documented and detailed and be subject to Governmental approval.

4.3.3.1 Technician Qualifications. Personnel equivalent to and representative of those who are anticipated to be operators on the equipment/system should be used in the HR demonstration. Equivalency should be assessed in terms of such variables as: experience, aptitude, and schooling. Physical characteristics, such as size and weight, should be considered whenever relevant.

Where possible standardized tests should be used to assure similarity between personnel in the test situation and in the operational military setting. The Armed Service Vocational Aptitude Battery (ASVAB) requirements and norms for personnel in comparable occupations in the military should constitute the basis for assessing the similarity of demonstration technicians to military personnel available for assignment to the equipment/subsystem/system. Both upper and lower limits should be considered.

In this regard, the contractor should submit for approval the ASVAB scores and the other factors to be considered in assessing equivalency, along with the criteria to be employed in establishing equivalency.

4.3.3.2 Technician Training. The system specific training given to the technicians who participate in the HR demonstration should not be greater in content or extent than that anticipated for training personnel who will man the system in actual operation.

Any system specific training received by the technicians who participate in the HR demonstration should be fully documented in terms of the specific content of the course and the time allotted for each topic. The criteria for evidence of mastery of the training program should also be specified. This information should be submitted at least 30 days prior to the demonstration and include training anticipated during the period between the submission and the HR demonstration.

4.3.3.3 Evaluator Selection. The HR demonstration administrators/evaluators should be supplied by the contractor and should have professional training in testing and relevant professional training or professionally supervised experience in administering performance tests. A background in industrial psychology is particularly germane to this requirement.

4.3.3.4 Evaluator Training. Each evaluator/administrator should be fully trained by the contractor in the areas of the testing in which he will be involved. This training should include an overview of the purpose and procedures of the demonstration, requirements for assuring standardization of conditions of testing and scoring, and typical errors. The evaluators should be appropriately trained in the operation of the equipment/subsystem/system under consideration. These training procedures should be fully documented and submitted along with the documentation of the technician training.

4.3.4 Control of Testing Conditions. All aspects of the testing conditions should be fully standardized. This includes, but is not limited to the: timing of the various sections of the tests, instructions given to the technicians, methods of dealing with questions that may arise, recording of anomalies, and the nature and method of collecting data. The objective aspects should be specified in writing. The less objective aspects should be described in writing and further described in the administrator/evaluator training period.

4.3.4.1 Demonstration Manual. To aid in achieving the goals of standardization and objectivity, a manual should be developed which contains all the demonstration conduct information necessary to assure these goals. The manual should contain all information necessary for orderly conduct of the demonstration including, but not limited to, unambiguous statements of the rules for conduct and standardization of the HR demonstration, the roles and specific responsibilities of the various participants, the time limits for each task, the rules and controls which will be observed, and the overall schedule. In case of conflict between the demonstration manual and these Guidelines, the Guidelines should pertain. The manual should be submitted to the Government for approval at least 45 days prior to the start of the HR demonstration.

4.3.4.2 Chief Test Administrator. The Government should appoint a Chief Administrator who represents the Government and who maintains administrative and control responsibility over the conduct of the HR demonstration. Decisions relative to the problems which arise during the conduct of the demonstration should be the responsibility of the Chief Administrator and be final.

4.3.4.3 Arrangement of Demonstration Area. The demonstration should be conducted in a private area which allows uninterrupted conduct of the required tests. While it is recognized that contractor and Governmental observers, representing various positions of responsibility in the development of the equipment/subsystem/system under development, will want to observe the demonstration, the comingling of persons actually involved in the demonstration with uninvolved observers should not be permitted. Similarly, the comingling of Governmental and contractor observers is discouraged. A suggested arrangement of the demonstration area is presented in Figure 6.

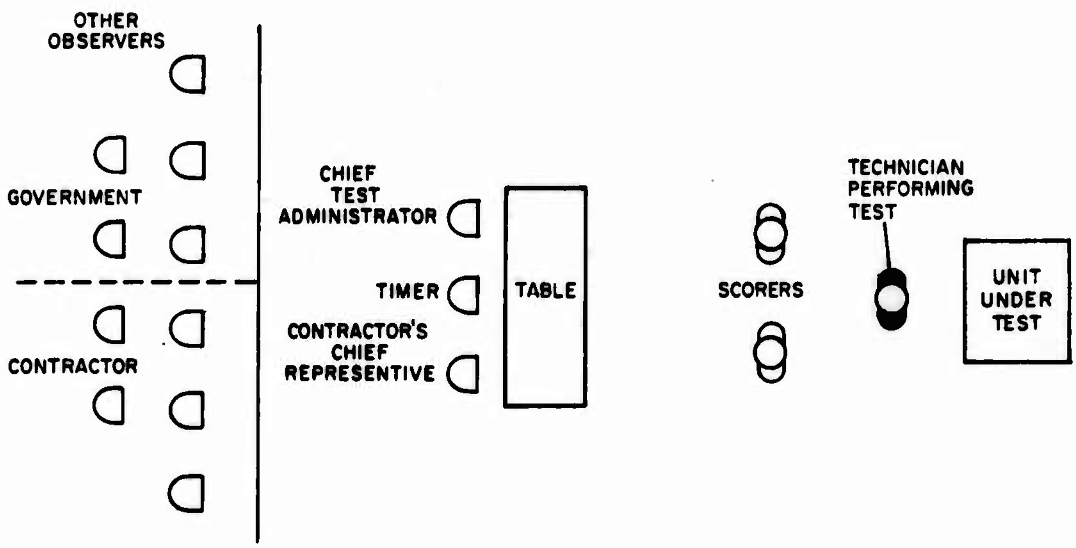

FIGURE 6. SUGGESTED ARRANGEMENT OF DEMONSTRATION AREA.

4.3.4.4 Timing. The total time for the completion of each demonstration task should be kept by an individual who is acceptable to both the Government and the contractor. In the event that the time for total task completion, as measured by this individual, does not agree with the time measured by the scorer(s), the Chief Administrator should reconcile the difference(s).

4.3.4.5 Engineering Support. Engineering support, test equipment, replacement parts, and the like, necessary for maintaining the equipment/subsystem/system under test in a proper operating condition during the HR demonstration, should be provided by the contractor.

4.4 Variations. It may not be possible to comply in every respect with the requirements detailed above. For example: (a) it may be extremely hazardous to have a technician perform certain tasks, (b) it may be impossible to simulate realistically the real world conditions under which one or several tasks will be typically conducted, or (c) training technicians (as described in section 4.3.3.2) may be prohibitive in terms of time or personnel available. In such cases, the contractor should propose a substitute (task, simulation, technician type, training, etc.) to attempt to meet the demonstration requirements. These proposals should describe and detail the reason for the substitute arrangements and the anticipated impact of these substitutions on the HR of the equipment/subsystem/system under test. The proposals should be implemented in the course of the final HR demonstration, if approved by the Government.

4.5 Control of Test Materials. The purpose of the HR demonstration becomes meaningless if the test materials are compromised in any way. The contractor should implement a strict control program to assure that the materials are compromised in no way and that the demonstration technicians have no prior specific information relative to demonstration and test content. Evidence of lack of control over test materials should constitute a basis for automatic failure of the demonstration.

4.6 Audit Trial. Throughout the development and implementation of the HR demonstration, considerable responsibility for integrity assurance rests with the contractor. However, a full audit trial should be left by the contractor so that the steps leading to the various end products can be fully evaluated by the Government. Such audit, at the option of the Government, may take place periodically over the various steps in HR demonstration development and may include actual interviews with participating personnel as well as review of supporting data and documentation.

5. Analysis and Reporting of Demonstration Data. The contractor should be responsible for analyzing and documenting the results of the HR demonstration. No extensive written report, in the sense of the usual "technical report," is necessary or desirable. Rather, a set of forms should be submitted which will contain the data accumulated during each step of the process. Examples of the required forms and their use are given below. Substitute forms containing essentially the same information as that shown, but differing in format, should be acceptable.

5.1 Time for Form Completion and Submission. Each form should be submitted immediately after its completion.

5.2 Forms. The categories of forms to be completed are:

Task identification and description (Form HR-1)--submitted during preparation phases.

Selection of demonstration tasks (Form HR-2)--submitted during preparation phases.

Human reliability demonstration data collection forms (Form HR-3)--submitted during preparation phase.

Human reliability, human availability, and human MTTR (Form HR-4)--submitted after demonstration.

Technician qualifications (Form HR-5)--submitted after demonstration.

Interrater reliability (Form HR-6)--submitted after demonstration.

5.2.1 Form HR-1. Form HR-1, or an equivalent, should be used for identification of the operator/maintainer involved tasks in the system, the frequency of occurrence of each task and the criticality of each task. All data required by this form should be provided.

5.2.2 Analyst(s). The name or names of the individual(s) completing the form(s) should be indicated.

5.2.3 Source of Data. The reference materials, specifications, reports, individuals, and so on used as information sources should be indicated.

5.2.4 Task Number. A unique identification number should be assigned to each task listed.

5.2.5 Name or Description. A prose description sufficiently detailed to distinguish between similar tasks should be entered for each task.

5.2.6 Equipment(s) Involved. The equipment units required for demonstrating performance of this task should be identified.

5.2.7 Frequency. The relative frequency of occurrence of each task should be identified. Frequency should be scaled in the same manner as criticality.

5.2.8 Criticality. The criticality of each task should be scaled as low (L), moderate (M), or high (H).

5.2.9 Duration. The nominal or expected duration of each task should be indicated in hours and minutes.

5.3 Selection of Human Reliability Demonstration Tasks.

5.3.1 Form HR-2. Form HR-2, or an equivalent, should be used to document the selection of the tasks to be sampled. Note that the goal here is to identify twice the number of tasks that will be included in the final HR demonstration.

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HUMAN RELIABILITY DEMONSTRATION FORM HR-1, TASK IDENTIFICATION AND DESCRIPTION

Date__________ Analyst(s)______________________ Source(s) of Data__________________

Task Number	Name or Brief Description	Equipment(s) Involved	Frequency	Criticality	Duration

Comments-(Identify reference point by *1, *2, etc.):____________________________________

Figure 7. Example of Form HR-1, Task Identification and Description.

5.3.2 Task Sorting. All task numbers entered on the Form HR-2 should be sorted into the appropriate frequency-criticality cell as demonstrated in the example of Section II, Form HR-2.

5.3.3 Task Total. The total number of tasks which fall in each level of criticality and each level of frequency should be computed and entered in the appropriate location in Section II of Form HR-2. The sum of the totals for each level of criticality must agree with the sum of the totals for each level of frequency and be equal to the total number of tasks.

5.3.4 Cross Product Total. The criticality and frequency level totals should be entered in the appropriate locations in Section III of Form HR-2. The appropriate criticality level total should be multipled by the appropriate frequency level total to produce a frequency-criticality cross product for each cell. In the example, the low criticality level total of 16 and the low frequency level total of 14, yields a resultant cross product equal to 224 (16 x 14= 224). This frequency-criticality cross product should be computed for each cell and the resultant value entered in the cell. The sum of the nine resulting cross products should be entered in the location labelled "Cross Product Total."

5.3.3 Desired Task Number Entry. The desired number of tasks to be selected should be entered in the location labelled "Number of Tasks to be Selected." Note that this number must be at least two times the number to be demonstrated. The actual tasks to be demonstrated will be 50 per cent random sample (without replacement of the selected tasks). The sample is drawn at the time of the demonstration.

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HUMAN RELIABILITY DEMONSTRATION FORM HR-2, TASK SELECTION FORM

Date________________ Analyst(s)______________________

____

____

____

SECTION I: LIST OF TASKS SELECTED

TASK NUMBER	DESCRIPTION

Figure 8. Example of Form HR-2, Task Selection.

SECTION II: FREQUENCY-CRITICALITY MATRIX

	FREQUENCY			
CRITICALITY	LOW	MODERATE	HIGH	TOTALS
LOW	*1 1,19,37,38,39	6,20,21,40,41 42	4,22,28,29,34	16 *2
MODERATE	10,14,15,16,17 18	2,8,36,43	3,5,27,35,44, 45,46,47,48,49 50	21
HIGH	11,12,13	7,9,30,31,32 33	23,24,25,26	13
TOTALS	14	16	20	

*1 Actual task numbers which fall in cell
*2 Total number of tasks in the respective row or column

SECTION III: FREQUENCY-CRITICALITY CROSS PRODUCTS

	FREQUENCY						
CRITICALITY	LOW		MODERATE		HIGH		TOTALS
LOW	224*2	3*4	256	3	320	4	16*1
MODERATE	294	4	336	4	420	5	21
HIGH	182	2	208	2	260	3	13
TOTALS	14		16		20	TOTAL	50
			CROSS PRODUCT TOTAL (CPT)				2500*3

NUMBER OF TASKS TO BE SELECTED (TTBS)= 30

$$\text{CELL WEIGHT} = \frac{\text{TTBS}}{\text{CPT}} = \frac{30}{2500} = .012$$

*1 - Row and column totals are taken from Section II
*2 - Cross product of row total and column total
*3 - Sum of cross products across all cells
*4 - Rounded product (to nearest integer) of cell weight and cell frequency-criticality cross product.

Figure 8. (con't.)

5.3.6 Cell Weight. The frequency-criticality cell weight should be computed as the number of tasks to be selected divided by the cross product total. The cell weight should be multiplied by the frequency-criticality cross product of each cell to determine the number of tasks to be selected from each cell. The resulting product should be rounded to the nearest integer. If more tasks are to be selected from a cell than are available for selection, then the tasks should be randomly selected, on the basis of relative proportions, from other cells.

5.3.7 Task Bank. The sample, as derived in 5.3, determines the task bank from which tasks are drawn for the HR demonstration. The names of the tasks in the task bank should be entered in Section I of Form HR-2 by number and description.

5.4 Form HR-3. Form HR-3 should be used to document the collection of human reliability demonstration data. There should be one such form developed for each task in the total sample to be available for the final demonstration (i.e., one form for each task listed in Section I of the HR-2 form). The nature of these forms is not prescribed. However, it is anticipated that the forms will be substantially similar to those presented in Figures 2, 3, and 4 of these Guidelines. Prior approval of the Government should be required for gross deviations from these forms. Regardless of the format employed, each form HR-3 should contain the information described below.

5.4.1 Observer. The name and any other relevant identification required to identify the observer who completed the form should be indicated. Only one person should be identified. If multiple observers are used, they should independently complete different forms.

5.4.2 Task Number. The task should be identified by a number which is the same as that listed for the task on Form HR-2.

5.4.3 Name of Task. The task should be identified by the same name as that listed on Form HR-1.

5.4.4 Technician Identification. Relevent identification of each technician involved in the task demonstration should be provided.

5.4.5 Time. Start and stop times for the task and subtasks (where appropriate) should be expressed in minutes and seconds.

5.4.6 Success or Failure. The outcome of each subtask should be criterion referenced and should be indicated as S or F (success or failure) or an equivalent.

5.4.7 Fix-Up. Subtask repetition on fix-up, necessitated by inadequate performance on the first attempt, is termed fix-up performance. Start time, stop time, and the success or failure of any fix-up attempts should be recorded. In the case of a failure on the fix-up, a second fix-up attempt should not be allowed.

5.4.8 Comments. Any unusual or potentially relevant observations, especially those which lend insight into the accuracy of the scoring and the validity of the observations, should be recorded. The reference point to the relevant sequenced subtask should be indicated by an asterisk (*) followed by a number (e.g., *1, *2, *3) if more than one comment is recorded.

5.5 Form HR-4. Form HR-4 or an equivalent should be used for calculating and reporting human reliability, human availability, and human mean time to repair.

5.5.1 Date. The date on which the form was completed should be entered.

5.5.2 Analyst. The name(s) of the individual(s) performing the data summarization and those who calculated the human reliability, human availability, and human MTTR values should be entered.

5.5.3 Number of Subtask Failures. The total number of failures of all subtasks demonstrated should be indicated. This number is determined by summing the number of subtask failures indicated on each HR-3 Form.

5.5.4 Number of Attempts. The number of attempts at performing all subtasks should be indicated. This number is the sum of both successes and failures, including fix-ups, across all HR-3 forms.

5.5.5 Human Reliability (HR). The human reliability yielded by the demonstration should be completed. For example, if the number of failures is equal to 41 and the number of attempts is equal to 503, then HR is equal to .92.

$$HR = 1 - \frac{\text{Number of Subtask Failures}}{\text{Number of Attempts}} = 1 - \frac{41}{503} = .918$$

5.5.6 Unmanned Station Hours. The number of unmanned station hours should be given. This value is the total time by which the demonstrated tasks extended beyond the nominal duration (and thereby could have caused delays in the performance of other jobs).

5.5.7 Total Mission Man Hours. The total mission man hours should be entered. This value is the total man hours taken to complete all tasks.

5.5.8 Human Availability (HAVAIL). The calculated human availability should be entered. If unmanned station hours is equal to 10 minutes and total mission man hours is equal to 240 minutes, then human availability is equal to .96.

$$HAVAIL = 1 - \frac{\text{Unmanned Station Hours}}{\text{Total Mission Man Hours}} = 1 - \frac{10}{240} = .96$$

5.5.9 Fix-Up Time. The total time spent in fix-up should be computed and entered.

5.5.10 Number of First Attempt Failures. The number of subtasks failed on the first attempt should be entered.

5.5.11 Human Mean Time to Repair (HMTTR). The human mean time to repair should be entered. This value is the amount of time spent, on the average, to fix-up tasks performed inadequately or unsuccessfully on the first attempt. If the total fix-up time is equal to 160 minutes and the number of failures is equal to 42, then HMTTR is equal to 3.81 minutes.

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HUMAN RELIABILITY DEMONSTRATION FORM HR-4, HUMAN RELIABILITY, HUMAN AVAILABILITY, AND HUMAN MTTR

Date______________________ Analyst(s)____________________________

Section I: Summary of Results

1. Obtained Human Reliability [ ]
2. Obtained Human Availability [ ]
3. Obtained Human MTTR [ ]

Section II: Detailed Calculations

HUMAN RELIABILITY (HR)
a= Number of subtask failures= [ ]
b= Number of subtask attempts= [ ]

$$HR = 1 - \left(\frac{a}{b}\right) = \boxed{}$$

HUMAN AVAILABILITY
a= USH= Unmanned station hours= [ ]
b= TMMH= Total mission man hours= [ ]

$$HAVAIL = 1 - \left(\frac{a}{b}\right) = \boxed{}$$

HUMAN MEAN TIME TO REPAIR (HMTTR)
a= Total time spent in fix-up= [ ]
b= Number of tasks failed on first trial = [ ]

$$HMTTR = \left(\frac{a}{b}\right) = \boxed{}$$

Figure 9. Example of Form HR-4, Human Reliability, Human Availability, and Human MTTR.

$$HMTTR = \frac{\text{Total Fix-Up Time}}{\text{Number of Failures}} = \frac{160}{42} = 3.81$$

5.6 Form HR-5. Information concerning the training and qualifications of the technicians participating in the demonstration should be recorded on Form HR-5, or an equivalent. There should be one Form HR-5 for each technician involved.

5.6.1 Date. The date of form completion should be entered on the form.

5.6.2 Page. Each Form HR-5 should be sequentially numbered and the total number of forms should be entered.

5.6.3 Analyst. The individual completing the form should be identified by name.

5.6.4 Source of Information. The records, forms, personnel or other sources consulted for obtaining the technician qualification information should be indicated.

5.6.5 Technician's Name. The name of the technician for whom the form pertains should be entered along with a unique code number.

5.6.6 Highest Educational Achievement. The highest grade level completed by the named technician should be indicated in the appropriate entry location. Equivalency attainments should be considered along with formal education.

5.6.7 Training and Experience Specific to System. The specific training and experience of the named technician in the theory, operation, and maintenance of the equipment/subsystem/system involved should be fully described.

5.6.8 Related Training and Experience. Any training and experience having implications to the tests on hand should be given here.

5.6.9 Technical and/or Vocational Training. All technical, vocational, and on the job training (including training on the current equipment/subsystem/system) completed by the named technician should be entered on the form HR-5.

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HUMAN RELIABILITY DEMONSTRATION FORM HR-5, TECHNICIAN QUALIFICATIONS

Analyst(s)______________________________ Date______________

Technician's Name__________________________ Code No.__________

Source(s) of Information ______________________
____
____
____

Highest Educational Achievement (grade level) __________

Technical and/or Vocational Training (date, schools, and course names)

DATE	SCHOOL	COURSE NAME

Training and Experience Specific to System

____
____
____
____

Related Training and Experience

____
____
____
____

Raw Scores, Percentile Equivalents, and Norms on Standardized Tests

TEST	RAW SCORE	PERCENTILE EQUIVALENT

COMMENTS: ____
____
____
____

Figure 10. Example of Form HR-5, Technician Qualifications.

5.6.10 Raw Scores, Percentile Equivalents, and Norms. Raw scores and percentile equivalents on standardized tests for the technician under consideration should be given along with a statement of the norms used to derive the percentile equivalents.

5.6.11 Comments. Any additional information relevant to the qualifications of the named technician, or his similarity to real system operators should be indicated. Additional pages may be added as required.

5.7 Form HR-6. Form HR-6, or an equivalent, should be employed for recording the data and computations used in determining interrater reliability.

5.7.1 Analyst. The name of the individual collecting the data and performing the calculations for the interrater reliability determination should be entered.

5.7.2 Task Number. The task identifying numbers, as indicated on Form HR-1 should be indicated in the appropriate location.

5.7.3 Evaluator. The score produced by each evaluator on each task considered within the interrater reliability evaluation should be entered.

5.7.4 Computations. The procedure used to calculate interrater reliability should be completely shown. Intermediate steps sufficient to verify the computations should be included.

5.7.5 Reliability. The computed interrater reliability should be entered. Any data available concerning the statistical significance of the reliability should be indicated.

5.7.6 Comments. Any remarks concerning the reliability data collection and calculation should be entered. Specific reasons for any severe discrepancies between judges should be entered, whenever known.

AN/__________SYSTEM

HUMAN RELIABILITY DEMONSTRATION FORM HR-6, INTERRATER RELIABILITY

Analyst____Date________________

TASK NUMBER	EVALUATOR 1	2	3	4	5

COMPUTATIONS

RELIABILITY= ________________________

COMMENTS:____

Figure 11. Example of Form HR-6, Interrater Reliability

5.8 Statistical Considerations. Since the total task population for an equipment/subsystem/system can not be tested in the HR demonstration, a statistical inference must be made concerning the attainment of the desired level of HR based on the sample of the events demonstrated. The goal of the statistical analysis of the HR demonstration data is to verify that the HR is equal to some specified level (within some tolerance and with a given level of confidence).

Any acceptable and standard statistical technique may be employed to establish within a 10 per cent confidence limit the error bounds around the human reliability attained in the HR demonstration. One method for accomplishing this is based on the standard error of the proportion of subtasks accomplished successfully during the demonstration and on the acceptable confidence interval.

If .895 is the required HR and an HR of .92 has been demonstrated, has the .895 requirement been met? The calculation is based on the standard error of the proportion and on the confidence range which is acceptable. The standard deviation of a proportion, σ, is equal to $\sqrt{pq}$ where p is the proportion of subtasks performed successfully and q is equal to 1 - p. In this case, $\sigma = \sqrt{.92 \times .08} = .271$. The standard error of proportion σ_p is equal to:

$$\frac{\sigma}{\sqrt{N}}$$

If we assume an N (i.e., number of subtasks) of 100, then σ_p is equal to .0271. Reference to a z table, (that is, a table of the normal distribution) indicates that 2.97 times the standard error will include 99 per cent of the population. Since 2.79 times .0271 is .076, we can say that we are 99 per cent confident that the real overall human reliability is between .844 (lower bound) and .996. Accordingly, the criterion of .895 HR has not been met. On the other hand, an N of 1000 had been involved, then the standard error of the proportion would be .009 ($.27\sqrt{1000}$. Since 2.79 times .0086 is .025, there is 99 per cent confidence that the value is between .895 and .942.

5.9 Determining the Required Level of HR. The required level of HR along with the confidence interval and level, should be specified by the Government. The required level will depend on many factors including but not limited to: the general role of the human in the situation under consideration and the effects of human failure on system/mission objectives, the nature of the equipment/subsystem/system under consideration, and the complexity of the tasks the human must perform.

5.10 Failure of the Final HR Demonstration. Satisfactory performance on the final HR demonstration is never certain prior to the demonstration. Prior to the onset of the HR demonstration, contingency plans should be submitted by the contractor for implementation in the event of failure to meet the predetermined HR criterion. Such plans should be subject to approval of the Government and probably involve redesign of the equipment/subsystem/system relative to the tasks contributing most heavily to the depressed HR along with scheduling of an additional HR demonstration at a later date. Because of failure of the HR demonstration may impact equipment acceptance, the earliest possible scheduling of the HR demonstration is advised.

5.11 Calculation of System Reliability, Availability, and MTTR. If equipment data are available they should be combined with the human data to provide overall system measures of reliability, availability, and MTTR.

5.11.1 **System Reliability (SR).** System reliability should be computed using the formula: (ER) x (HR)

where:

ER = equipment reliability
HR = human reliability

5.11.2 System Availability (SA). System availability should be calculated using the formula: $SA = 1 - \left(\frac{DT}{UT+DT} + \frac{USH}{TAMH} \right)$

where:

DT = Down time
UT = Up time
USH = Total time (in man hours) demonstration tasks are extended beyond nominal time
TAMH = Total man hours available

5.11.3 System MTTR. System mean time to repair (SMTTR) should be calculated using the formula:

$$SMTTR = \frac{TDT + TFU}{NFU + (NR)}$$

where:

TDT = total equipment down time during the demonstration

TFU = the total amount of time spent in subtask fix-up attempts during the demonstration

NFU = the total number of subtask fix-ups attempted during the demonstration

NR = the total number of equipment repairs during the demonstration

For example, if the total equipment down time was 5 hours, the time spent in subtask fix-up was 2 hours, a total of 12 fix-ups was performed, and 5 repairs were performed:

$$SMTTR = \frac{5 + 2}{12 + 5} = .412$$

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